ARTERIAL EMBOLISM IN THE LIMBS

THE CLINICAL PROBLEM AND ITS ANATOMICAL BASIS

by

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E. & S. LIVINGSTONE LTD
EDINBURGH AND LONDON
1959

'. . . et quomodo (si ligaveris arterias) statim partes non modo torpent, frigent et quasi pallidae cernentur sed et alitandem desinunt?'

WILLIAM HARVEY (1628)

PRINTED IN GREAT BRITAIN

FOREWORD

EMBOLIC obstruction of the main arteries of the limbs has interested physicians and surgeons for at least 250 years. In theory, the treatment of choice should be surgical because removal of the embolus is the only way in which a normal circulation can be restored, but in practice physicians and surgeons interested in peripheral arterial diseases have treated many of their patients without operation. This monograph, based upon an extensive personal experience, describes the train of events both clinical and pathological which follow embolic obstruction of the arteries of the limbs and goes a long way towards establishing a rational approach to the problem of treatment.

A gap in our knowledge of peripheral arterial disease has been a careful and detailed study of the clinical picture and eventual outcome in a large group of patients with an embolic obstruction of an artery in the limbs. Physicians and surgeons have so far had to rely upon a limited personal experience or on written opinions which have not always been backed by adequate factual information This want has now been met.

Dr Jacobs concludes his discussion with a list of 24 main conclusions and all of these contain information of great value to those who undertake the care of patients with arterial emboli. As a surgeon I have found the selection of patients for operation to be the crux of the problem. Many patients develop spontaneously or as a result of conservative treatment an efficient collateral circulation, the problem is to predict when this is not going to happen. Dr Jacobs gives the answer in one clear and concise sentence 'in limbs with adequate collateral circulation, signs of grave ischaemia do not persist for more than two hours after onset' It is the number of clear, informative, well thought out and useful statements of this type that makes this book such a valuable contribution The author is to be congratulated.

C. G. ROB

PREFACE

THERE have been numerous published studies of limb embolism but nearly all of them have relied on case material collected from the records of many different observers The present study is based on clinical and morbid anatomical material gathered over a period of sixteen years by a single observer. As far as possible, clinical observations have been verified by detailed post-mortem study, errors in diagnosis and prognosis have been analysed and early clinical signs have been correlated with the final outcome. An attempt has been made to assess the value of various methods of treatment by comparison of the outcome in treated and untreated cases. A summary of the main conclusions is given in the final chapter.

I am grateful to the London County Council, who made part of the work possible by providing X-ray facilities for me in the autopsy department at the Whittington Hospital. My thanks are also due to a number of my colleagues at the Hospital. Many of them kindly allowed me to see cases of vascular occlusion in their wards and for this I am indebted to Dr Michael Ashby, Dr Arnold Bloom, Professor W. W. Davey, Dr A N. Exton-Smith, Dr T St M Norris, Dr H. E S. Pearson and Mr J. Marshall Scott Dr A. B Bratton and Dr S. Robinson and their colleagues of the Histological Department carried out some of the autopsies and mounted and photographed autopsy specimens. Pathological tests were performed by Dr J. M. Alston and his colleagues in the Group Clinical Laboratory. My former senior registrar Dr K. C. Robinson and a long series of my house physicians have helped me in the clinical observation of my patients.

Miss K R. Askwith and other members of the radiographic staff have given me much help with the processing of X-ray material and our photographer Miss Elizabeth Mason has been most generous with her time and skill. Mr E. F. Baldwin assisted me with the practical work of post-mortem arteriography and my secretary Miss S. Glushanock has helped me in innumerable ways.

I would also like to acknowledge the courtesy and patience shown by Messrs E. and S. Livingstone and particularly by Mr Charles Macmillan.

1959 A. L. JACOBS

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ILLUSTRATIONS

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Historical Note

HARVEY'S *De Motu Cordis* was published in 1628 and it was not long after this that the first references to arterial embolism began to appear in medical writings. One of the earliest is that of William Gould of Oxford, in whose paper ' An account of a Polypus found in the heart of a person that died EPILEPTICAL at OXON ' (1684) the following passage appears:

> . . an Apoplexy insues; which disease will also more dangerously happen, *when some particles of a polypus in the left ventricle of the heart*, broken off by the violent stream of *blood*, shall be impacted into the *carotid arteries at their insertion into the brain*, whence all intercourse of spirits will irrecoverably be stopt

The same idea is expounded in the *Commentaria* of Gerard van Swieten of Leyden (1742), for example in Section 1010:

> It was proved from several observations that those polypi sometimes grew to the fleshy pillars of the heart, and afterwards happen to be separated from thence, and be propelled together with the blood into the pulmonary artery, or the aorta, and its larger branches, so as either to streighten them very much, or entirely stop them up. . and if they happen to stick in the carotid and vertebral arteries, they must disturb the functions of the brain, and entirely abolish them, if they altogether intercept the passage of the arterial blood to that organ
>
> (English translation, London, 1744)

Senac (1749) described the process of thrombosis, distinguished between ante-mortem and post-mortem clots and gave a good account of the process of arterial embolism.

In 1776, Jussieu, Paulet, Saillant and Teissier presented at the Académie Royale de Médecine, Paris, a paper entitled 'Mémoire sur les gangrènes des membres dans les affections cardiaques et vasculaires ' Legroux (1827) pointed to the resemblance between a blood-clot found in the left auricle and one occluding the brachial artery and suggested that the latter was a detached fragment of the former. In 1856 he also described a clinical case of peripheral embolism which he had observed in 1836. In 1828, Alibert published a Paris thesis entitled: *Occlusion peu connue des vaisseaux artériels considérée comme cause de gangrène.*

The foundations of our knowledge of the morbid anatomy of arterial embolism were laid by Virchow in a series of classical publications beginning in 1846 and it was he who first used the term ' embolism '. The following concise and lucid description is from *Beitrage zur speciellen Pathologie und Therapie* (1854):

> In contradistinction to locally formed thrombus, due to clotting of the blood *in situ*, I reserve for the clot which migrates (or rather is propelled) into a more distant vessel the term ' Embolus '. This distinction is the more necessary in that bodies other than blood-clots, *e g.* fragments of degenerated heart valves, may be carried into remote vessels Further, as I have described in detail elsewhere, the impacted clot *serves as a nucleus for the formation of new clot in its neighbourhood*, so that we very commonly find the embolus enclosed within a much larger thrombus (P. 167)
>
> The site of the embolism depends upon the relation between the size of the detached body and the diameter of the vessel large bodies are soon held and impacted in larger branches, while smaller ones are carried further, sometimes into very fine branches. (P 167)
>
> As I described previously, emboli cause a partial obliteration of the vessel, which is patent immediately above and below, and at the outset the clots lie quite unattached in its lumen. Emboli can be distinguished from locally formed thrombi by the following characteristics. they lie quite loosely in a vessel with a perfectly healthy wall, yet they show evidence of considerable age. (P. 168)

During the same period, and apparently without knowledge of Virchow's work, Kirkes of St Bartholomew's Hospital was investigating the same problem and the results of his studies appeared in an admirable paper in 1852 He gave descriptions, both clinical and post-mortem, of several typical cases of multiple embolism, exemplifying all the forms: cerebral, peripheral, visceral and pulmonary. Kirkes also described ' micro-embolism ' in endocarditis and embolism from thrombosed aneurysm Rokitansky (1842–6) had already described visceral infarcts and had emphasised their association with endocarditis but he thought the thrombi were formed locally

During the second half of the nineteenth century, clinical and post-mortem accounts of embolism accumulated in the literature, for example those of Tufnell (Dublin, 1853), Gaultier de Claubry (Paris, ? 1853), Schultzenberger (Strasbourg, 1856), Wilkin (Staplehurst, 1868) and Duguet (Paris, 1879). In 1860, Cohn of Berlin published a comprehensive work on ' embolic vascular disease '. Beaudet of Paris published his much-quoted thesis: *Gangrène des membres dans les affections cardiaques* in 1882. The earliest account of ischaemic muscle paralysis and contracture seems to be that of Chvostek (1892).

One of the earliest attempts at treatment was made by Deroyer of Paris in 1880. He treated a case of aortic embolism by external massage, with the aim of driving the thrombus down into the iliac arteries, where he thought it would offer less threat to the circulation of the lower limbs. The first true operation for embolus was carried out by Sabaneyev of St Petersburg in 1895. He attempted

embolectomy in a woman of 28 years, suffering from ulcerative endocarditis. After the femoral artery had been opened, the patient collapsed and it had to be resutured without removal of the embolus but she survived 19 days and autopsy revealed no secondary thrombosis at the site of the arteriotomy. The first completed embolectomy was performed by Moynihan in 1903 (recorded in 1907). He removed an embolus from the popliteal artery in a woman of 41 years but the result is not fully described in his paper. Another early British embolectomy was performed by Sampson Handley, who devised the operative technique of retrograde aspiration employed some years later by the Swedish surgeons. Other early attempts at embolectomy were made by Doberauer (Prague, 1907), Stewart (U.S.A., 1907) and Murphy (U S A., 1908).

The first completely successful embolectomy (femoral) was the achievement of Georges Labey of Paris in 1911. Mosny and Dumont (1911), in reporting this case, gave principles of indication for the operation which would probably be acceptable to many surgeons of today:

> Vascular embolism may therefore now be reckoned among the medico-surgical disorders, provided certain conditions be satisfied: that operation be undertaken without delay, that the embolus be aseptic and easily accessible, that the patient be young and his arteries healthy

After this French success, the operation was taken up with brilliant enterprise and technical skill by the Swedish surgeons, Einar Key foremost among them. In his classical paper of 1922, the first comprehensive work on embolectomy, Key gave details of eight cases operated upon by himself, together with a number from other Swedish surgeons About the same time Bull (1921) published an account of the morbid anatomy of limb embolism, based on the records of 15 cases found among more than 6,000 autopsies at Oslo. Bauer of Malmo successfully removed an embolus from the aortic bifurcation in 1913. Despite the pioneer work of Moynihan and Sampson Handley, the first successful British embolectomy was not recorded until 1925, by Jefferson of Manchester.

The work of the Swedish surgeons aroused great interest in embolism and a total of 382 Swedish operations had been recorded by 1936 Numerous papers began to appear in other countries and many of them concerned themselves mainly with the possibilities of embolectomy (*e g* Mason and Warren (1931), Pearse (1933), Danzis (1933), Nystrom (1936)) An admirable monograph, giving a more comprehensive account of the subject was published in 1937 by Haimovici of Marseilles The more recent general works on peripheral embolism include those of McClure and Harkins (U S A , 1943), Reynolds and Jirka (U S A., 1944), Leriche (France, 1947), Warren and Linton (U S A., 1948), Haimovici (U.S A , 1950), Richards (U K., 1954) and Jepson (U K., 1955).

The theory of embolic arteriospasm seems to have been conceived during the period 1910–25 by a number of different observers, partly as a result of

observations at embolectomy, partly from experimental observations such as those of Ebbecke (1923). This theory has always presented great attractions to the French surgeons, many of whom regard arterial spasm as the main factor in the production of ischaemia. The operation of arteriectomy, designed to remove possible sources of irritation in the adventitial nervous plexus, which were believed to excite reflex vasospasm, was initiated by Tixier in 1907 and Leriche advocated it as a treatment for embolism, when seen too late for embolectomy. This operation has never found much favour in Britain or the U.S.A. In some recent publications, the theory of embolic arteriospasm is regarded with more scepticism (Richards (1954), Jepson (1955)).

Interest in the vasomotor aspects of arterial ischaemia led the French surgeons to apply methods of abrogation of the sympathetic nerve supply of the limbs, either surgical extirpation of the lumbar or cervical ganglia or infiltration with local anaesthetics, and their initiative has been widely followed elsewhere

Attempts have also been made to influence vasomotor reactions in embolism by the use of chemical vaso-dilators Villaret and Justin-Bezançon (1926) used acetyl-choline and papaverine (suggested for the treatment of traumatic arterial spasm by Schaffer in 1921) was introduced for the treatment of embolism by Denk in 1934 In recent years the benzylimidazoline derivatives have also been used (Zothe (1939), Singer (1940)).

This ' physiological ' approach to the problem of embolism led to an unwarrantable disregard of the anatomical aspects of collateral circulation, especially among French observers Leriche went so far as to discount the classical writings of the eighteenth-century anatomists on arterial anastomoses. On the basis of a study made by dissection of 18 foetuses (Rassat (1922)), Leriche declared that the macroscopic anastomoses described by anatomists were largely non-existent and that collateral circulation must depend upon minute arterial ramifications of ' pre-capillary ' order During the past thirty years the classical anatomical teachings have been vindicated (e g. by Olovson (1941)), though our knowledge of natural and pathological variations in the anatomy of collateral circulation is still very incomplete.

The introduction of anticoagulant therapy offered a method of combating consecutive thrombosis in embolism. Heparin, discovered in 1918 by Howell and MacLean, was first used in human therapy by Craafoord of Stockholm in 1937. Dicoumarol, discovered by Link and his colleagues in 1941, was first used in the treatment of thrombosis by Allen, Barker and Waugh (1942) and it has been succeeded by other oral anticoagulants.

In the period following the First World War, numerous special technical aids have been introduced for the study of vascular disorders. They include the aneroid oscillometer (Pachon (1909), Cawadias (1916)), capillary microscopy (Lombard (1912), Weiss (1916), Denk (1934)), arteriography (Dos Santos (1929)), the fluorescein test (Herrlin, Glasser and Lange (1942)), the radio-

active sodium test (Smith and Quimby (1945)) and the tonoscillometer (Ejrup (1944)). Most of these technical aids have been applied to the study of limb embolism but they have not contributed greatly to diagnosis or assessment, which still rest on relatively simple methods of clinical examination

Apart from new methods of study and therapy, there has been some broadening of our clinical understanding of the symptomatology, course and prognosis of acute arterial occlusion. The possibility of spontaneous recovery was well recognised by early observers, for example Goodisson (1818) and Barth (1837), who both described cases of occlusion of the aortic bifurcation without gangrene. Attention was redirected to it by some of the French writers (Roque and Chalier (1909), Fiolle (1936), Haimovici (1937)) A further advance in clinical understanding, illuminated by experience of air-raid injuries in the Second World War, was recognition of the fact that ischaemic muscle necrosis in embolism, apart from its local effects in the limb, can occasionally produce renal ' crush syndrome ' in the acute stage (Glen (1941), Guthkelch (1943), Bywaters and Stead (1945)).

Despite the developments of the past thirty years, the present position of limb embolism as a clinical and therapeutic problem is not altogether clear and there is still much difference of opinion on the value of various forms of treatment. The attitude to embolectomy varies from enthusiasm (' One of the most satisfactory operations that can be performed. . .' (Key, 1936)) to disillusionment (' . cette opération décevante et illusoire ' (Grégoire, 1939)) There are many publications in which large numbers of cases have been studied but in nearly all of them the cases have been collected from records made by many different observers Among problems which still remain incompletely resolved are.

- The general incidence of limb embolism.
- Special aetiological factors
- Diagnostic problems, especially localisation of an embolus.
- The causation, extent and influence of consecutive thrombosis.
- Natural recovery rates in embolism at different sites
- The genesis of ischaemia, the roles of anatomical variations and of vasomotor factors.
- The effect of treatment and the place of embolectomy.

In the present study these problems have been approached, not by the application of any new technical methods but by clinical and morbid anatomical study of a series of cases of limb embolism, all of them under the care of a single observer The conclusions drawn are based almost entirely upon this personal experience.

II

Material and Methods of Study

THE present study is based on clinical and morbid anatomical material observed at three general hospitals in London during the period 1938 to 1954. The material comprises three main groups:

1. A series of clinical cases of limb embolism.
2. A further series of patients suffering from mitral stenosis, examined for evidence of old arterial occlusions in the limbs and compared with a control series of patients without heart disease
3. An anatomical study of arterial collaterals made on human cadavers by post-mortem arteriography.

Clinical cases of limb embolism

The general nature of this material is shown in Table 1. There were 122 incidents of limb embolism in 69 patients. 69 of these incidents were seen in the acute ischaemic phase (*i.e.* within 7 days of onset). There were 55 deaths and 48 autopsies. In a majority of the autopsies a full dissection of the affected limb arteries was made to determine the nature, sites and extent of the occlusions. In a certain number, post-mortem arteriography was carried out before the autopsy and the arteriograms were compared with the arterial specimens subsequently dissected.

TABLE 1

Clinical cases of limb embolism

Total number of patients		69
Surviving at time of report		14
Dead at time of report.		55
Number of autopsies.		48
Number of embolic incidents		
Anatomically verified	85	
Established on strong clinical grounds	30	
Doubtful embolism:	3	
'Pseudo-embolism':	4	
Total:	122	

Stage of observation:	
Seen within 10 hours of onset *	33 incidents
Seen 10 to 24 hours after onset	14 incidents
Seen 24 to 48 hours after onset	10 incidents
Seen 2 to 7 days after onset	12 incidents
Seen 7 to 14 days after onset	5 incidents
Seen more than 14 days after onset	48 incidents
Total:	122 incidents
Multiplicity of embolic incidents	
One recognisable embolic incident	32 patients
Two recognisable embolic incidents	25 patients
Three recognisable embolic incidents	10 patients
Four recognisable embolic incidents	2 patients

* 'Onset' in this and all subsequent pages means the onset of acute ischaemic symptoms

The clinical material has been analysed for information relating to various problems:

Aetiology:	Chapter IV
General morbid anatomy:	Chapter V
Clinical features:	Chapter VI
Diagnosis	Chapter VII
Outcome and prognosis	Chapter VIII
Treatment:	Chapter XII

Evidence of old arterial occlusions in mitral stenosis

In addition to the cases of limb embolism observed clinically, a further series of 269 patients, all suffering from mitral stenosis, were examined for evidence of old occlusions in the limb arteries. The findings are compared with a control series of 300 patients in the same age and sex grouping, not suffering from heart disease. In the patients with mitral stenosis the history was also enquired into, to determine whether there had been any acute or chronic ischaemic symptoms in the past

Approximately 2,900 autopsy records in one hospital were examined to determine the incidence of visceral embolism in cases showing evidence of mitral stenosis.

These two groups of material are discussed in Chapter III.

Anatomical study of arterial collaterals

Clinical experience shows great variation in the ischaemic effects and outcome of embolic arterial occlusions in the limbs One important consideration is the possibility of variation, natural or pathological, in the extent of anatomical development of arterial collaterals at different sites and in different persons. To

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Total.	122	

III

The Incidence of Limb Embolism in Mitral Stenosis

MOST writings on limb embolism are based on the observation of patients admitted to hospital for acute ischaemic symptoms or those who have developed such symptoms while already in hospital for treatment of heart disease During the course of this study, some patients of the latter type were seen in whom the ischaemic symptoms were mild and transient and who appeared likely to recover even without treatment (*e.g* Cases Nos 11 (R axillary), 29 (L common iliac), 34 (R common femoral), 50 (L. brachial), 56 (L. axillary), 75 (R. brachial)).

It was also noted during routine examination of patients with mitral stenosis that some of them showed pulse deficiencies, particularly in the lower limbs Haimovici (1950) and Richards (1954) have recorded observations of this kind Enquiry into the history of such patients sometimes disclosed that they had had acute or chronic ischaemic symptoms in the past

With the aim of acquiring some information on the general incidence of limb embolism and on the frequency of recovery in untreated cases, systematic palpation of the limb pulses was made a routine in unselected consecutive cases of mitral stenosis. In each case, after the condition of the limb pulses had been recorded, the patient was questioned about ischaemic symptoms in any of the limbs at any time in the past.

A total of 269 patients with mitral stenosis were examined in this way. For comparison, a series of 300 hospital patients not suffering from heart disease were similarly examined These controls were selected so as to have approximately the same age and sex distribution as the cases of mitral stenosis but were otherwise chosen at random, concurrently with the cases of mitral stenosis

Routine of examination

The limbs were examined by palpation only and in each case six pairs of arteries were palpated:

obtain some information on this, an anatomical study was made of 66 human cadavers, using arterial ligation to imitate embolic occlusions and subsequent injection of contrast fluid to demonstrate arterial collaterals by radiography. The results of this study are described in Chapter IX.

Arterial spasm in limb embolism

Many writers believe that the ischaemic effects of an embolic arterial occlusion may be aggravated by a state of active arterial spasm, set up by impaction of the embolus. Chapter X is devoted to a discussion of this theory, the evidence for it being critically examined and tested as far as possible by the experience of this study.

1. Brachial—against the middle of the shaft of the humerus.
2. Radial—at the wrist
3. Common femoral—at the groin.
4. Popliteal—against the upper end of the tibia with the knee semi-flexed.
5. Dorsal pedal—against the tarsus.
6. Posterior tibial—behind the medial malleolus.

Pulse deficiencies

We have to enquire whether deficiencies in the limb pulses, as determined by palpation, can be accepted as satisfactory evidence of arterial occlusion Absence of a single foot pulse is frequently observed in normal persons (Morrison (1933), Silverman (1946)). The findings in our own series of control patients confirm this (Table 2) Pulse deficiencies in the foot were therefore regarded as significant only if both pulses were absent in the same foot. The radial pulse is rarely absent in normal persons and absence of this pulse was therefore accepted as significant The pulse deficiencies found were classified as follows:

Significant: Impalpable brachial pulse
Impalpable radial pulse.
Impalpable femoral pulse.
Impalpable popliteal pulse
Impalpable dorsal pedal and posterior tibial pulses in one foot.

Non-significant: Impalpable dorsal pedal pulse when posterior tibial pulse in the same foot is present.
Impalpable posterior tibial pulse when dorsal pedal pulse in the same foot is present.

Pulse deficiencies in control patients

The incidence of 'significant' and 'non-significant' pulse deficiencies found in the series of 300 control patients is recorded in Table 2. The figures can be summarised:

'SIGNIFICANT' PULSE DEFICIENCIES

All ages, 15–79 years (total 300):	2 persons (0·7%)
Arteries concerned.	Popliteal in both instances

'NON-SIGNIFICANT' PULSE DEFICIENCIES

Age group 15–39 years (total 95):	31 persons (32·6%)
Age group 40–79 years (total 205).	71 persons (34·6%)
All ages, 15–79 years (total 300):	102 persons (34·0%)

'Significant' pulse deficiencies were therefore rare in patients without

Table 2

Routine palpation of the limb pulses

Pulse deficiencies in 300 control patients (no heart disease)

'Non-significant' pulse deficiencies	Incidence of pulse deficiencies in 2 age groups			
	15–39 years (total 95 persons)		40–79 years (total 205 persons)	
	Number of persons	% of age group	Number of persons	% of age group
One posterior tibial pulse impalpable	12	12·6	17	8·3
One dorsal pedal pulse impalpable	5	5·3	7	3·4
Two posterior tibial pulses impalpable	7	7·4	33	16·1
Two dorsal pedal pulses impalpable	7	7·4	12	5·9
Dorsal pedal pulse impalpable in one foot and posterior tibial in the other	—	—	2	1·0
All varieties	31	32·6	71	34·7
'Significant' pulse deficiencies				
Both pulses in one foot impalpable	—	—	—	—
Both pulses in both feet impalpable	—	—	—	—
One popliteal pulse impalpable	1*	1·0	1†	0·5
Femoral pulse deficiencies	—	—	—	—
Upper limb pulse deficiencies	—	—	—	—
All varieties	1	1·0	1	0·5

* This case had both dorsal pedal pulses impalpable but posterior tibial pulses were palpable. Included in fourth line above.

† All foot pulses were palpable in this case.

TABLE 4

Routine palpation of the limb pulses

Patients with mitral stenosis

Group (2) 172 patients with auricular fibrillation

Incidence and age distribution of 'significant' pulse deficiencies

Age group	Number in age group			Number with 'significant' pulse deficiencies	% of age group
	Male	Female	Persons		
15–19 years	—	—	—	—	—
20–29 years	—	6	6	4	(66 6)
30–39 years	4	13	17	3	17 6
40–49 years	13	39	52	10	19 2
50–59 years	5	48	53	13	24·5
60–69 years	4	24	28	11	39 3
70–79 years	3	13	16	6	37 5
All ages	29	143	172	47	27 3

Anatomical distribution of 'significant' pulse deficiencies found

Number of limbs affected	
One limb	30 patients
Two limbs	16 patients
Three limbs	1 patient

Arteries affected	
Subclavian	1 instance
Axillary	1 instance
Common iliac	10 instances
Common femoral	23 instances
Popliteal	30 instances

The incidence of 'non-significant' pulse deficiencies found in the same two groups, after exclusion of the patients who showed 'significant' pulse deficiencies, is recorded in Table 5.

Group 1. PATIENTS WITH REGULAR HEART RHYTHM

Table 3 shows that 'significant' pulse deficiencies were not very common in this group Four examples were found in the total of 97 patients; *i.e.* 4·1%. In 2 of the 4 patients both lower limbs were affected and a total of 4 popliteal arteries and 2 iliac arteries were found to be occluded in the group

If we exclude the 4 patients with 'significant' pulse deficiencies a total of 93 patients remain in this group. 'Non-significant' pulse deficiencies were

heart disease. Only two instances were found in 300 persons, both popliteal. On the other hand, 'non-significant' pulse deficiencies were found in one-third of the total and were equally common in older and younger persons

It seems justifiable to accept pulse deficiencies of 'significant' type as evidence of arterial occlusions.

Pulse deficiencies in patients with mitral stenosis

The 269 cases were divided into two groups:

Group 1. 97 patients with regular heart rhythm.
Group 2. 172 patients with auricular fibrillation.

The incidence of 'significant' pulse deficiencies found in these two groups is recorded by age groups in Tables 3 and 4.

TABLE 3

Routine palpation of the limb pulses

Patients with mitral stenosis

Group (1) 97 patients with regular heart rhythm

Incidence and age distribution of 'significant' pulse deficiencies

Age group	Number in age group			Number with 'significant' pulse deficiencies
	Male	Female	Persons	
15–19 years	2	5	7	—
20–29 years	3	29	32	1
30–39 years	2	21	23	—
40–49 years	3	13	16	—
50–59 years	3	9	12	—
60–69 years	3	3	6	2
70–79 years	—	1	1	1
All ages	16	81	97	4

Anatomical distribution of 'significant' pulse deficiencies found

Number of limbs affected
One limb 2 patients
Two limbs. 2 patients

Arteries affected
Common iliac: 2 instances (or aorta 1)
Popliteal: 4 instances

frequently than in Group 1—in 44·8% (as compared with 32·3%) and some old embolic occlusions of the smaller arteries may account for this.

Relative incidence of embolism at different anatomical sites

The evidence bearing on this question is discussed in the section on morbid anatomy (Chapter V).

History indicating previous embolism

When questioned, a number of the patients with mitral stenosis gave a clear description of an acute ischaemic syndrome, lasting some days and passing

TABLE 6

Routine palpation of the limb pulses

269 patients with mitral stenosis

Incidence of histories indicating previous embolism

Type of history	Patients with 'significant' pulse deficiencies	Patients with 'non-significant' pulse deficiencies	Patients without any pulse deficiencies
Clear history of acute ischaemic symptoms	13	2*	1
Clear history of chronic ischaemic symptoms	8†	—	1
Doubtful history of chronic ischaemic symptoms	5	4	—
History of former cerebral embolism	8†	3*	6
History unreliable (patient confused)	2	—	—
History completely negative	16	78	124
Total number in group	51	86	132
Number giving positive history	33	8	8
Incidence of positive histories in group	64·7%	9·3%	6·1%

* One patient common to these two groups.

† One patient common to these two groups

present in 30 of them, or 32·3%. This proportion is similar to that in the control patients.

TABLE 5

Routine palpation of the limb pulses

'Non-significant' pulse deficiencies in patients with mitral stenosis

(Patients with 'significant' pulse deficiencies excluded)

Type of '*non-significant*' pulse deficiency	93 patients with regular heart rhythm		125 patients with auricular fibrillation	
	Number of patients	% of group	Number of patients	% of group
One dorsal pedal pulse impalpable	5		5	
One posterior tibial pulse impalpable	5		10	
Two dorsal pedal pulses impalpable	6		6	
Two posterior tibial pulses impalpable	14		33	
One dorsal pedal and one posterior tibial pulses impalpable in opposite feet	—		2	
All varieties	30	32·3%	56	44·8%

Group 2. PATIENTS WITH AURICULAR FIBRILLATION

In this group, 'significant' pulse deficiencies were present in 47 patients out of 172, or 27·3% (Table 4) The table shows an increasing incidence of these arterial occlusions with increasing age, rising to 39·3% in the age group 60–69 years. The occlusions were found much more commonly in lower limbs than in upper limbs. This may be because in upper limb embolism the distal pulses often return quite soon, whereas in lower limb embolism they are often *permanently* abolished (Chapter VIII) A total of 65 occluded arteries were found in this group, 35 of them being large arteries (iliac, femoral, subclavian, axillary), while 30 were popliteal. Old embolic occlusions of arteries smaller than the popliteal or brachial are not revealed by the method of examination; they would be classified as 'non-significant' pulse deficiencies.

'Non-significant' pulse deficiencies were found in Group 2 rather more

TABLE 7

Incidence of systemic internal embolism in mitral stenosis

Evidence from autopsy records

Total number of autopsy records:	2,900 (approx.)
Number of cases of mitral stenosis:	212
Number of these showing internal embolism:	110 (52%)
Death directly due to embolism	38 (18%)
Embolism a contributory cause of death.	11 (5%)
Embolism present but non-contributory.	61 (29%)
Cases in which death was directly due to embolism:	
Cerebral embolism:	25 cases
Embolism of aortic bifurcation:	6 cases
Mesenteric embolism:	4 cases
Embolism of common iliac artery:	1 case
Embolism of coronary artery:	1 case
Embolic obturation of stenotic mitral valve:	1 case
Total	38 cases

CONCLUSIONS

The evidence considered in this chapter indicates that embolism of the major limb arteries, popliteal or larger, is of relatively frequent occurrence in patients with mitral stenosis and auricular fibrillation. The liability to embolism appears to be much less in patients with regular heart rhythm.

In many of the patients these embolic occlusions cause transient acute ischaemic symptoms, but recovery follows without any treatment.

In a not inconsiderable number the ischaemic symptoms are so slight as to leave no lasting memory.

off gradually. Some patients described typical intermittent claudication, persisting for many months. Statements about habitual coldness of the feet were received with more caution, for many women will complain of this. Habitual coldness of a single limb was accepted for the category 'doubtful history'. A clear history of a former cerebral embolism was recorded as 'positive'.

The results of this enquiry are shown in Table 6, the groups compared being (1) patients with 'significant' pulse deficiencies, (2) those with 'non-significant' deficiencies and (3) those without any pulse deficiencies. The two latter groups both show a low incidence of 'positive' histories but in the group with 'significant' pulse deficiencies the incidence of 'positive' histories was 64·7%.

In some patients it was possible subsequently to verify the fact that a symptomless pulse deficiency in a limb was indeed due to an old embolic occlusion (e.g. Cases Nos. 42, 51, 72, 75. See Figs. 1, 2, 3).

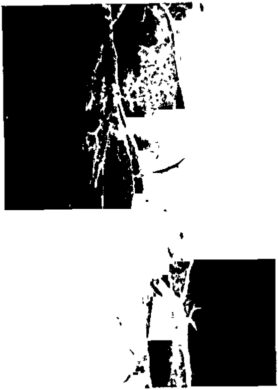
General incidence of embolism—autopsy evidence

Bull (1921) found 15 cases of limb embolism in a total of more than 6,000 autopsy records at Oslo. However, it is not usual for the limb arteries to be fully examined at autopsy and autopsy records therefore do not usually give reliable evidence of the overall incidence of limb embolism. On the other hand, evidence of internal embolism, particularly in the brain, spleen and kidneys, is regularly recorded.

The incidence of systemic internal embolism as revealed at autopsy will be higher than that of limb embolism as determined by palpation of the limb pulses during life, for the following reasons. Firstly, visceral infarcts recognisable at autopsy may be caused by occlusion of quite small arteries, whereas palpation will not reveal occlusion of any arteries smaller than the brachial or popliteal. Secondly, palpation is unlikely to reveal more than a proportion of the embolic occlusions in upper limbs (Chapter VIII).

Bearing these considerations in mind, it is of interest to compare the incidence of pulse deficiencies found in the limbs in life with that of cerebral and visceral infarcts found at autopsy in patients suffering from the same type of heart disease. A total of approximately 2,900 autopsy records at the Whittington Hospital, extending over the period 1946 to 1955, was therefore examined to determine the incidence of cerebral or visceral embolism in all cases in which there was unequivocal post-mortem evidence of mitral stenosis. The findings are shown in Table 7. Fifty-two per cent of all cases of mitral stenosis showed post-mortem evidence of systemic internal embolism. Making allowance for the factors discussed in the previous paragraph, this figure agrees quite well with the figure of 27·3% for 'significant' limb pulse deficiencies in patients with mitral stenosis and auricular fibrillation examined during life.

FIG 2 (*Case No 42*)
Embolism of left popliteal artery Post mortem arteriography Unreduced print of region of popliteal division



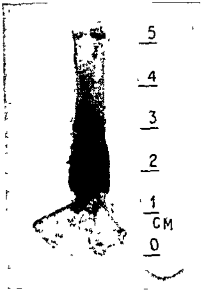


FIG 3 (*Case No 42*)
Embolism of left popliteal artery. Autopsy specimen Lower end of left popliteal artery and its division into anterior and posterior tibial arteries, showing old adherent embolus

CASE NO. 42. *Embolism of left popliteal artery.*

A woman aged 26 years, suffering from mitral stenosis with auricular fibrillation and congestive heart failure. Routine examination showed absence of both pulses in the left foot, but she could remember no ischaemic symptoms. At autopsy, nine months later, post-mortem arteriography showed a short occlusion at the lower end of the left popliteal artery, with a collateral circulation so good that injection of the left foot was as complete as that of the right (Fig 1) Exploration of the left popliteal artery revealed an old adherent embolus at the lower end (Fig 3)



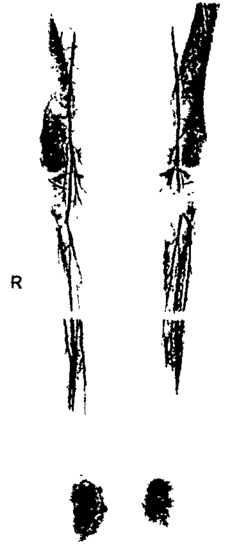


FIG 1 (*Case No 42*)
Embolism of left popliteal artery Post-mortem arteriography of both lower limbs

This difference is in large measure due to the higher proportion of cases of rheumatic heart disease in the present series; i.e. 63% of all patients, as compared with 40% in Haimovici's series.

TABLE 8

Age and sex distribution of 69 patients who had limb embolism

Age group	Male	Female	Persons	% of all patients
20–29 years	2	5	7	10·1%
30–39 years	2	3	5	7·3%
40–49 years	1	6	7	10·1%
50–59 years	4	15	19	27·6%
60–69 years	3	14	17	24·6%
70–79 years	5	9	14	20·3%
All ages	17	52	69	100·0%

Under 40 years. 12 patients (17·3%)
Over 40 years 57 patients (82·7%)
Over 60 years 31 patients (44·9%)

TABLE 9

Sex and age of occurrence in series of 122 embolic incidents

Age group	Male	Female	Incidents	% of all incidents
20–29 years	3	8	11	9·0%
30–39 years	3	5	8	6·6%
40–49 years	1	9	10	8·2%
50–59 years	5	25	30	24·6%
60–69 years	6	31	37	30·3%
70–79 years	9	17	26	21·3%
All ages	27	95	122	100·0%

Under 40 years. 19 incidents (15·5%)
Over 40 years. 103 incidents (84·5%)
Over 60 years. 63 incidents (51·6%).

IV

Aetiology

THE problem of aetiology in arterial embolism has two aspects: firstly, the general principles of aetiology, which relate to the type of patient in whom embolism is liable to occur and, secondly, the problem of the direct cause which produces embolism in a particular patient at a particular time. Various factors such as congestive heart failure, exertion, infections and drug treatment have been discussed by other authors.

GENERAL AETIOLOGICAL PRINCIPLES

Sex and age

The series of clinical cases of limb embolism showed a considerable preponderance of females:

PATIENTS:	Male:	16	(23·2%)
	Female.	63	(76·8%)
EMBOLIC INCIDENTS·	In male:	27	(22·1%)
	In female:	95	(77·9%)

The preponderance of females is due mainly to their higher incidence of mitral stenosis:

CASES WITH MITRAL STENOSIS:	Male:	8 incidents	(10·4%)
	Female:	69 incidents	(89·6%)
CASES WITHOUT MITRAL STENOSIS:	Male	19 incidents	(42·2%)
	Female:	26 incidents	(57·8%)

Other published series do not all show the same sex distribution, for example:

WARREN AND LINTON (1948)	(Collected series of 97 patients)	
	Male·	52·5%
	Female:	47·5%
HAIMOVICI (1950)	(Collected series of 228 patients)	
	Male:	45%
	Female:	55%

This difference is in large measure due to the higher proportion of cases of rheumatic heart disease in the present series; i.e. 63% of all patients, as compared with 40% in *Haimovici's* series.

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Age and sex distribution of 69 patients who had limb embolism

Age group	Male	Female	Persons	% of all patients
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Over 40 years: 103 incidents (84·5%)
Over 60 years: 63 incidents (51·6%)

Table 8 shows the age and sex distribution of the 69 patients of the writer's series. (The age in patients who had more than one embolic incident is taken as the mean between the age at the first incident and that at the last.) Table 9 shows the distribution of age of occurrence and sex in the 122 embolic incidents of the series.

If the age distribution shown in Table 8 be compared with those of the series of Warren and Linton and that of Haimovici, certain differences are again apparent:

WARREN AND LINTON (1948)	(95 patients with age recorded)	
Under 40 years:	14 patients	(13·7%)
Over 40 years:	81 patients	(86·3%)
Over 60 years:	*27* patients	*(28·4%)*
HAIMOVICI (1950)	(228 patients)	
Under 40 years:	44 patients	(19·3%)
Over 40 years:	184 patients	(80·7%)
Over 60 years	*69* patients	*(30·3%)*
PRESENT SERIES	(69 patients)	
Under 40 years	12 patients	(17·3%)
Over 40 years	57 patients	(82·7%)
Over 60 years	*31* patients	*(44·9%)*

The present series shows a considerably higher proportion of the older patients (over 60 years of age). This is probably due to differences of selection of material, perhaps related to the type of hospital in which the patients were seen (some of the cases recorded by Haimovici were seen in private practice). The writer's material shows increasing tendency to embolism with rising age. Nineteen embolic incidents occurred in 12 patients under 40, while 63 incidents occurred in 31 patients over 60. This finding corresponds well with the incidence of pulse deficiencies at different ages in the limbs of patients with mitral stenosis, recorded in Chapter III.

Heart disease

Analysis of the incidence and types of heart disease is shown in Table 10 and the incidence and types of cardiac arrhythmia in Table 11. Two facts stand out:

1. Only a single incident of the whole series occurred in a patient who had no heart disease (he had acute miliary tuberculosis—Case No. 48)
2. 121 embolic incidents occurred in patients with heart disease and in 98 of these (81%) there was an auricular arrhythmia of major type—usually auricular fibrillation, occasionally flutter or paroxysmal tachycardia.

TABLE 10

Heart disease in 122 embolic incidents

Type of heart disease	Number of incidents	Number with major* auricular arrhythmia
Mitral stenosis alone	58	55
Mitral stenosis plus rheumatic aortic lesion	7†	6
Mitral stenosis plus bacterial endocarditis	10†	—
Mitral stenosis plus syphilitic aortic lesion	3	3
Bacterial endocarditis, no previous valvular lesion	3	—
Aortic lesion alone	—	—
Hypertensive heart disease	11	11
Hypertensive heart disease plus myocardial infarction	5	5
Myocardial infarction	9	3
Coronary disease without myocardial infarction	4	4
Thyrotoxicosis	6	6
Major arrhythmia of unknown causation	5	5
Subacute myocarditis (? toxoplasmosis)	1	—
No heart disease	1	—
All embolic incidents	122	98

* Auricular fibrillation, auricular flutter or auricular paroxysmal tachycardia
† One incident common to these two groups

There were 23 incidents in which the heart rhythm was either regular or showed only minor arrhythmia (ectopic beats) In 20 of these there was some form of heart disease producing inflammatory changes in the endocardium, namely bacterial endocarditis, myocardial infarction or myocarditis In the remaining 3 incidents the patients had mitral stenosis and in 2 of them there was over-dosage of digitalis (see below) These findings correspond closely with the separate investigation on pulse deficiencies in the limbs of patients with mitral stenosis, recorded in Chapter III In that series, patients with auricular

Table 8 shows the age and sex distribution of the 69 patients of the writer's series. (The age in patients who had more than one embolic incident is taken as the mean between the age at the first incident and that at the last.) Table 9 shows the distribution of age of occurrence and sex in the 122 embolic incidents of the series.

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series, among a total of 122 embolic incidents there were 31 in which congestive failure was present at the time of the embolism and 5 in which the patient had been in failure at some prior time. More than 70% of all embolic incidents occurred in patients who had never been in failure.

Influence of exertion

It has been supposed that undue exertion in a patient with heart disease might tend to precipitate embolism. However, Sprague and Westinghausen (1941) and Bourne (1950) found that there was no special relation between exertion and embolism. In the present series there was a total of 53 embolic incidents in which information was available as to the state of activity of the patient at the time of onset of the symptoms of embolism:

Patient active at time of onset.	7 incidents
Patient resting at time of onset:	46 incidents

These figures support the conclusion of the above-mentioned authors that there is no special relation between exertion and arterial embolism. Indeed, they suggest the contrary—that embolism is more likely to occur at times of minimum activity of the heart. It has already been pointed out that the association of embolism with changing heart rhythm is not very common. These two facts are not consistent with the commonly held conception of embolism as a result of detachment or fragmentation of a previously adherent intracardiac thrombus This matter is discussed in Chapter V (' Character of embolic thrombi ').

Influence of non-cardiac disease

It has often been stated that systemic disease, especially acute infections, may be a factor in the causation of embolism (Key (1922), Haimovici (1937)). This is not borne out by the present series, in which the incidence of non-cardiac disease was low Only one incident occurred in a patient entirely free from heart disease. This patient had acute miliary tuberculosis but no thrombosis of pulmonary veins was found at autopsy (Case No. 48)

Non-cardiac disease was present only in 16 out of the total of 122 embolic incidents and in all but one of these there was also an adequate cardiac cause for embolism. Conditions which produce dehydration, for example high fever, vomiting or acute enteritis, may well act as precipitating factors in patients with heart disease. In one of the cases, embolism occurred soon after a severe attack of diarrhoea (Case No. 50).

Influence of digitalis

Haimovici (1937) mentioned a number of earlier authors who had discussed the effect of digitalis, ouabaine and quinidine in precipitating embolism. Re-establishment of normal auricular rhythm by quinidine has been thought to

TABLE 11

Cardiac arrhythmia in 103 embolic incidents

Type of arrhythmia		Number of incidents
Auricular fibrillation		91
Auricular flutter		1
Auricular paroxysmal tachycardia		6
Auricular ectopic beats.	With bacterial endocarditis	2
	With myocardial infarction	1
	With mitral stenosis	1
Ventricular ectopic beats	With myocarditis	1
All incidents with arrhythmia		103

fibrillation had an *incidence of 27·3% of arterial occlusions in the limbs*, while in those with regular heart rhythm the incidence was only 4·1%

It follows from these figures that if bacterial endocarditis and myocardial infarction can be excluded, a diagnosis of arterial embolism is rarely justified in a patient with regular heart rhythm.

Changing heart rhythm

Embolism was observed in close relation to a change of heart rhythm only in 3 patients. One, a case of mitral stenosis, had intermittent attacks of auricular tachycardia, *with 3 separate embolic incidents (Case No. 44)*. One had iliac embolism during the course of a prolonged attack of auricular paroxysmal tachycardia (Case No 21). The third patient had auricular fibrillation. After treatment by rapid digitalisation the heart rhythm became regular and about 5 days later there was an embolism of the brachial artery. Four months later auricular fibrillation recurred and persisted. After a further interval of three months there was simultaneous embolism of both lower limbs (Case No 20).

SPECIAL AETIOLOGICAL FACTORS

Congestive heart failure

Haimovici (1937) suggested that embolism occurs more easily in ' decompensated ' cardiac cases and this seems a reasonable assumption In the present

ticular, in close relation to *over-dosage* of this drug. The relation between digitalis treatment and embolism is shown in Table 12.

Embolism in over-digitalised patients

This group comprises 13 embolic incidents in 11 patients (Cases Nos. 11, 15, 20, 29, 47, 49, 58, 63, 65, 66, 78). The duration of the symptoms of over-dosage of digitalis at the time of the embolism varied from 2 days to 8 days. Five of the 11 patients had been in good health and free from heart failure when they developed signs of over-dosage, followed shortly afterwards by embolism. Four patients had developed congestive failure and were treated by rapid digitalisation methods with resultant over-dosage symptoms, followed soon afterwards by embolism If we exclude patients with bacterial endocarditis, there were only 3 embolic incidents in patients who had mitral stenosis but no serious auricular arrhythmia. Two of these occurred in one patient who had symptoms of over-dosage of digitalis (Case No 58).

The figures in Table 12 do not, of course, provide statistical evidence of a relation between digitalis treatment and embolism. Nevertheless, they suggest that rapid digitalisation, and especially over-dosage of digitalis, may precipitate systemic embolism. Patients with auricular fibrillation are always liable to form thrombi in the left auricle and this may well be facilitated by excessive slowing of the ventricular action and reduction of cardiac output It does not therefore seem necessary to demonstrate changes in blood coagulability before this conception can be accepted

One patient, whose heart disease had for years been under good control, became over-digitalised and soon after this she had multiple systemic embolisms. Autopsy showed very soft black thrombi in several arteries and unattached thrombi of very similar type in the left auricle. All these thrombi were obviously of very recent formation and as the only recent change in the heart condition had been the development of over-dosage of digitalis it would be very rash to dissociate the two phenomena (Case No. 66).

Apart from over-dosage of digitalis, too vigorous treatment of patients with congestive heart failure, either by digitalis or by mercurial diuretics, may introduce the factor of haemoconcentration stressed by Pere. In all, it must be concluded that over-zealous treatment of heart failure may well play some part in the causation of peripheral embolism.

act by causing detachment or fragmentation of thrombi already adherent in the left auricle. In the writer's view, embolism more commonly results from recently formed thrombi which have never become adherent (Chapter V—'Character of embolic thrombi'). *In connection with the possible effects of* treatment, interest has centred mainly on the influence of digitalis preparations.

Macht (1943) and Werch (1943) concluded from experimental studies that the coagulability of the blood in cats and rabbits was increased by administration of digitalis. De Takats, Trump and Gilbert (1944) described three cases of peripheral embolism in patients who had had excessive dosage of this drug and Reynolds and Jirka (1944) and Massey and Steiner (1944) reported similar cases. De Takats and his colleagues also found experimentally that administration of digitalis produced an increase in heparin tolerance both in animals and in man

Subsequent workers have contested these findings. Levin and Ruskin (1949) studied the coagulation mechanism in healthy human subjects before and after administration of digitoxin, both orally and intravenously; they concluded that the drug had no effect. Cathcart and Blood (1950) investigated normal human subjects and patients suffering from congestive heart failure and found no significant changes in clotting time or prothrombin time following administration of digitalis Pere (1951) found that increase in coagulability occurred only when digitalis (or strophanthin or mercurial diuretics) produced *diuresis* in patients suffering from congestive heart failure. He concluded that this was due to haemoconcentration. Daley and his colleagues (1951), in a study of the clinical records of 194 patients who had had systemic embolism, concluded that there was '. . no evident relation between digitalis therapy and embolism'

In this study, a number of cases were observed in whom peripheral embolism *occurred in close relation to newly initiated digitalis treatment* and, in par-

TABLE 12

Relation of peripheral embolism to digitalis treatment

Particulars of digitalis treatment		Number of incidents
No digitalis treatment prior to embolism		28
Established digitalisation (appropriate dosage)		63
Newly digitalised	Slowly	2
	Rapidly	*7**
Over-dosage of digitalis		13
All incidents with adequate record		113

* *In one instance, 3 weeks before the embolism.*

TABLE 14

Anatomical sites of limb embolism in series from five authors

Anatomical site	Petitpierre (1928) 129 cases	Danzis (1933) 129 cases	Key (1936) 382 cases	Warren, Linton & Scannell (1954) 240 cases	Haimovici (1950) 330 cases
Axillary	7·7%	5·4%	11·8% (Axillary and Brachial)	24·6% (Axillary and Brachial)	4·5%
Brachial	7·7	14·7			9·1
Aortic	9·3	8·5	4·5	12·5	9·1
Iliac	20·1	17·8	17·2	12·5	16·6
Femoral	44·5	40·3	54·4	33·3	38·5
Popliteal	7·7	9·2	11·3	13·8	14·2

series may be compared with that in published series from five other authors, shown in Table 14.

This series shows a lower incidence of femoral embolism, a higher incidence of popliteal and a somewhat higher incidence of iliac embolism than most of the others. There must be a difference, either of accuracy of diagnosis of the site of embolism or of selection of cases. Selection depends to some extent on the type of hospital in which the cases have been observed. Surgical considerations will also affect it, for cases chosen for operation may include a higher proportion of the more serious grades of ischaemic syndrome and, as will be shown later, selection of this type will introduce an anatomical bias.

All the series published by the other authors show a low incidence of popliteal embolism but there is no reason why the popliteal artery should be less liable to embolism than the femoral. Probably small thrombi are more often formed in and discharged from the heart than larger ones and embolism should therefore be commoner in smaller arteries than in larger ones. The numerous small infarcts found in viscera at autopsy support this assumption. It is because popliteal embolism so often causes very mild ischaemic symptoms, and therefore escapes attention, that it is relatively uncommon in most of the published series. This view is supported by the findings as to pulse deficiencies in the limbs of patients with mitral stenosis, recorded in Chapter III. Among a total of 71 arterial occlusions found in such patients, 34 (48%) were popliteal. These occlusions are selected in that they have all recovered spontaneously and popliteal embolism will tend to figure prominently in such a group.

V

Morbid Anatomy

Anatomical sites of embolism

In a total of 118 embolic incidents (4 instances of 'pseudo-embolism' excluded), 106 occurred at main bifurcations and 12 elsewhere. These 12 comprised 7 in the superficial femoral artery, 2 in the deep femoral, 2 in the external iliac and one in the upper popliteal. The anatomical sites of embolism in the 118 incidents are shown in Table 13. The incidence of the various sites in this

TABLE 13

Anatomical sites of embolism in 118 incidents

Anatomical site of embolism	Whole series		85 incidents, all anatomically verified	
	Number	%	Number	%
Axillary	8	6·8	4	4·7
Brachial	14	11·8	10	11·7
Aortic	17	14·4	15	17·7
Common iliac	24 } 26	20·4 } 22·1	17 } 19	20·0 } 22·4
External iliac	2	1·7	2	2·4
Common femoral	16 } 23	13·6 } 19·5	10 } 17	11·8 } 20·0
Superficial femoral	7	5·9	7	8·2
Deep femoral	2	1·7	2	2·3
Popliteal	27	22·9	17	20·0
Posterior tibial	1	0·8	1	1·2
All sites	118	100·0	85	100·0

For lower limb embolism, combination of the two series gives a total of 160 arterial occlusions and the incidences of the different anatomical sites in the combined group are as follows:

Aortic:	10·6%
Iliac:	22·6%
Femoral.	28·7%
Popliteal	38·1%

The frequency here rises steadily with decreasing size of the artery.

Multiple embolism

The total of 122 embolic incidents gives an average of nearly two for each patient. In Chapter IV it was shown that the tendency to multiple embolism increases with increasing age Multiple embolic occlusions in a single limb were seen in 20 patients and embolic occlusions in more than one limb in 34 patients (aortic embolism has not been counted as multiple limb embolism) These 34 cases showed the following:

Embolism of two limbs separately·	25 patients
Embolism of three limbs separately	7 patients
Embolism of all four limbs:	2 patients

Associated embolism in sites other than the limbs was also very common. In 48 autopsies on patients with limb embolism the following examples were found:

Visceral embolism.	34 patients
Cerebral embolism:	24 patients
Cerebral and visceral embolism.	11 patients
Pulmonary embolism:	15 patients

Character of embolic thrombi

Since Virchow's original description of embolic thrombi, it has usually been assumed that emboli should show the characters of thrombi of some standing, firm in consistency and red or partially decolorised (' caillot blanc '). This conception results from the view that embolism is usually caused by detachment or fragmentation of an adherent mural thrombus which has been present for some time in the left auricle. It appears likely that embolism is more often caused by thrombi of very recent formation which have never become adherent at all. This view is supported by the fact that a number of separate embolic occlusions so often occur successively in the same patient within a relatively short period The initial factor must be an increased tendency to thrombosis in the left auricle. Some of the resultant thrombi become adherent; others pass out into the arteries. The presence of adherent thrombi, for example in the

Some cases of iliac embolism are wrongly diagnosed as femoral, because of persistence of the femoral pulse (Chapter VI). The error was made several times in this study (Chapter VII) and it might figure more frequently in a collected series.

From first principles, we might expect embolism to be commonest in small arteries and rarest in large ones. Yet none of the published series shows this relation and in the present series, though it does show a higher incidence of popliteal embolism, the incidences of popliteal, femoral and iliac embolism are substantially the same. The additional selective factor influencing the site incidence in observed series must be the severity of the symptoms. The tendency to embolism may be greatest in the smallest arteries but it is also in these arteries that the ischaemic symptoms are least severe and they therefore figure less frequently in clinical series than in actual occurrence

Assuming that the pulse deficiencies found in patients with mitral stenosis represent old embolic occlusions in which there has been spontaneous recovery, we might combine these occlusions with the series of clinically observed embolisms and so perhaps obtain a closer approximation to the natural site incidence than is represented by the clinical series alone. This has been done in Table 15.

TABLE 15

Incidence of embolism at different anatomical sites

Combined series of clinically observed embolisms and old arterial occlusions in other patients with mitral stenosis

Anatomical site of embolism	Clinical series	Old arterial occlusions	Combined figures	% of limb total
Upper limbs				
Axillary	8	2	10	41·7
Brachial	14	—	14	58·3
All upper limbs	22	2	24	100·0
Lower limbs				
Aortic	17	—	17	10·6
Iliac	26	10	36	22·6
Femoral	23	23	46	28·7
Popliteal	27	34	61	38·1
All lower limbs	93	67	160	100·0

CONSECUTIVE THROMBOSIS

Introduction

The local thrombosis which may occur in an artery after it has been occluded by an embolus has been variously termed 'secondary thrombosis', 'propagating thrombosis', 'thrombose extensive', 'caillot prolongé' and 'consecutive thrombosis'. The last term, used by Richards (1954), seems to be the most satisfactory and the term 'secondary thrombosis' can be reserved for thrombosis occurring after embolectomy

The process of local consecutive thrombosis was described by Virchow It has been regarded by many as an important adverse factor and in recent years it has been usual to treat peripheral embolism with anticoagulants in the hope of preventing it. There is great variation in the extent and rapidity of formation of consecutive thrombus in different cases of embolism Surgeons have found it at operation as little as two hours after the onset of symptoms; at other times it has been absent after periods as long as 43 hours (Key (1922)). Examples have been described in which the length of consecutive thrombus was as much as 115 cm after 10 hours (Rohde (1933)) or as little as 1·5 cm after 8 days (Wideroe (1922)).

It is natural to presume that the ischaemic effects of the localised arterial occlusion produced by an embolus must be aggravated by a process which greatly extends the length of artery occluded and therefore restricts the part of the main arterial trunk beyond the occlusion which can take part in the collateral circulation. Ivanov (1928), in experiments on artificial embolism, showed that the liability to gangrene in his experimental animals was increased by increasing the length of the occluded segment of the main arterial trunk However, it is not easy to prove in any case of human embolism that gangrene has been precipitated by consecutive thrombosis Even if an association can be shown between extensive consecutive thrombosis and gangrene, it could still be argued that this thrombosis might be the *result* of inadequacy of the collateral circulation rather than its cause The problem is a complex one. Firstly, the embolus itself has been supposed to act as a 'centre of coagulation', particularly when it is a septic clot Secondly, pathological changes in the arterial intima at the site of the embolus, or ischaemic intimal damage more distally, might provoke thrombosis Thirdly, the degree of filling and of stagnation in the arterial trunk distal to the embolus must play some part If collateral circulation be very poor, the arterial system beyond the occlusion may be almost completely emptied of blood very soon after impaction of the embolus. In such a case there might be very little consecutive thrombosis distal to the embolus, even though gangrene ensues. Instances of this were seen in this study. (See later in this chapter.) If there be a scanty collateral circulation, the arteries beyond the occlusion will receive blood but its flow will be very sluggish and this may

auricular appendage, in patients who have had embolism is a phenomenon of association rather than one of causation and the absence of such adherent thrombi at autopsy in no way discounts the conclusion that a peripheral arterial occlusion is embolic in character.

If this conception of the embolic process be correct, then emboli, when seen soon after their impaction in peripheral arteries, should show the characters of recent thrombi rather than old ones. In the writer's experience this is usually the case. The thrombi found at operation are commonly soft enough to remove by suction through a distally placed incision. In 5 cases of embolectomy the thrombi removed were soft and black (Cases Nos 7, 8, 20, 45, 66). Patients who died very soon after the occurrence of embolism showed thrombi of similar type at autopsy. This was well exemplified by Cases Nos. 64 and 66. Case 64 had soft black thrombi in 8 separate arteries, while the only thrombus in the left auricle was firm, decolorised and adherent; it was obviously of much greater age. Case 66 had soft black thrombi in 5 separate peripheral arteries and several similar unattached thrombi in the left auricle, one impacted into the stenotic mitral valve If the artery be examined more than a few days after the embolism, the embolus will have changed in character and may then have the appearance of an older clot.

Iselin and de Balsac (1948) drew attention to the rarity of ' caillot blanc ' in patients operated on for embolism. They described cases in which at operation they found the artery filled with thickened, ' pitch-like ' blood. As a result of this experience these authors elaborated a theory of ' primary arterial paralysis ' with subsequent local thrombosis ('. . . le phénomène primitif initial est l'arrêt des battements artériels, la formation des caillots n'étant que secondaire ') Some of the cases described by these authors may well have been examples of true embolism by clots of very recent formation and it is not necessary to accept the theory put forward, which runs counter to the whole vast body of evidence of the embolic process

Presence of intracardiac thrombi

Left-sided intracardiac thrombi were found in 29 of the 48 patients who came to autopsy. These were distributed as follows:

In the left auricle:	17 patients
On the valves:	8 patients
In the left ventricle:	4 patients

The exact location of thrombi within the left auricle has not been adequately documented in the writer's material. Jordan, Schiefley and Edwards (1951) have studied this problem and their findings are discussed in Chapter XII (' Operations on the heart ').

TABLE 16

Proximal consecutive thrombosis

10 examples from 34 autopsies (64 embolised limbs)

Case No	Site of embolus	Time interval from embolism to autopsy	Length of proximal thrombus	Character of proximal thrombus
9	R. common femoral	11 days	2 cm	Soft, recent, filling lumen
10	R superficial femoral	1–2 years	2 cm	Soft, recent, filling lumen
30	Aortic bifurcation	Several weeks	12 cm	Old, firm ' pillar thrombus ', apex free
31	Aortic bifurcation	6 days	7 cm	Soft, recent, filling lumen
50	Aortic bifurcation	4 years	2 cm	Old conical thrombus, apex free
52	Aortic bifurcation	32 days	5 cm	Firm black conical thrombus, apex free
61	Mouth of R common iliac	1 year +	3 cm	Old, unilateral, on adjacent aortic wall
61	L common femoral	1 year +	5 cm	Soft, recent, filling lumen
67	Mouth of R common iliac	2 years	3 cm	Old, unilateral, on adjacent aortic wall
69	Mouth of L common iliac	15 months	4 cm	Old, unilateral, on adjacent aortic wall

phase. For example, in one case the embolus at the aortic bifurcation was surmounted by a ' pillar thrombus ' nearly 12 cm long, rounded and unattached at its apex and bearing on its surface transverse striations suggesting deposition of successive layers (Case No. 30; see Figs. 10 and 30). Two other thrombi in the lower aorta had this ' stalagmite ' appearance (Cases Nos. 50 and 52). There was one case of aortic embolism in which proximal consecutive thrombus appeared to have formed rapidly after the embolism, it filled the lower segment of the aorta completely and obstructed the inferior mesenteric and lower lumbar arteries (Case No. 31). This consecutive thrombus may have affected collateral circulation but there was no other example in which this appeared likely.

In the three examples not involving the aorta the proximal consecutive thrombus was in the femoral artery In all of them it was slight in extent, appeared to have been formed terminally and could have had no effect on the outcome.

cause extensive consecutive thrombosis. The factor of stagnation may also be influenced by the efficiency of venous outflow from the limb, which will be impaired if thrombosis occurs (as it often does) in the deep veins.

The anatomical conformation of the system of arterial collaterals is probably of considerable importance. If this is such as to permit re-entry into the main trunk a short distance beyond the embolic obstruction, then the 'segment of stagnation' will be short and the extent of distal consecutive thrombosis is likely to be short also. On the other hand, it is conceivable that in some limbs the collateral system may be so constructed as to provide an adequate circulation to the distal part of the limb without requiring the participation of a long segment of the main arterial trunk. In such a case the 'segment of stagnation' will be relatively long and we might then find a consecutive thrombus of considerable length, even though the limb has survived. Instances of this were also observed. (See later in this chapter.) Changes in blood coagulability probably also play some part.

Available autopsy material

There were 34 autopsies in which a full examination of the limb arteries was made in order to establish the full extent of the consecutive thrombosis. From these autopsies, information was obtained relating to a total of 64 embolised limbs (Cases Nos. 4, 6, 9, 10, 13, 14, 17, 25, 29, 30, 31, 37, 42, 44, 45, 46, 47, 48, 50, 51, 52, 53, 55, 59, 61, 67, 69, 72, 74, 75, 76, 78, 80, 81). In 12 of these cases the nature and extent of the thrombi are illustrated by diagrams (Appendix I). In some cases the arteries were photographed (Figs. 3, 6, 8, 9). In Cases Nos. 42, 48, 53, 61, 69 and 75, post-mortem arteriography was carried out before the arteries were examined (Figs. 1, 2, 4, 5, 7). The following sections are based on the findings in these 34 autopsies.

EXTENT OF CONSECUTIVE THROMBOSIS IN 34 AUTOPSIES

Consecutive thrombosis may occur proximal to an embolus, distal to an embolus or between two emboli. The three forms will be considered separately.

1. Proximal Consecutive Thrombosis

Consecutive thrombosis proximal to an embolus is usually slight and unimportant. In the 34 post-mortem arterial dissections only 10 examples were found. The relevant information is condensed in Table 16, which shows that in 7 of the 10 examples the proximal thrombosis occurred in the lowest part of the aorta, the embolus being either at the aortic bifurcation or in the mouth of the common iliac artery. In 6 of these, the site, character and conformation of the consecutive thrombus indicated that it was formed by a process of slow growth and could therefore have had no appreciable influence in the acute ischaemic

TABLE 16

Proximal consecutive thrombosis

10 examples from 34 autopsies (64 embolised limbs)

Case No.	Site of embolus	Time interval from embolism to autopsy	Length of proximal thrombus	Character of proximal thrombus
9	R. common femoral	11 days	2 cm	Soft, recent, filling lumen
10	R. superficial femoral	1–2 years	2 cm	Soft, recent, filling lumen
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31	Aortic bifurcation	6 days	7 cm	Soft, recent, filling lumen
50	Aortic bifurcation	4 years	2 cm	Old conical thrombus, apex free
52	Aortic bifurcation	32 days	5 cm	Firm black conical thrombus, apex free
61	Mouth of R common iliac	1 year +	3 cm	Old, unilateral, on adjacent aortic wall
61	L common femoral	1 year +	5 cm	Soft, recent, filling lumen
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69	Mouth of L common iliac	15 months	4 cm	Old, unilateral, on adjacent aortic wall

phase. For example, in one case the embolus at the aortic bifurcation was surmounted by a 'pillar thrombus' nearly 12 cm long, rounded and unattached at its apex and bearing on its surface transverse striations suggesting deposition of successive layers (Case No. 30, see Figs. 10 and 30). Two other thrombi in the lower aorta had this 'stalagmite' appearance (Cases Nos 50 and 52). There was one case of aortic embolism in which proximal consecutive thrombus appeared to have formed rapidly after the embolism; it filled the lower segment of the aorta completely and obstructed the inferior mesenteric and lower lumbar arteries (Case No. 31). This consecutive thrombus may have affected collateral circulation but there was no other example in which this appeared likely

In the three examples not involving the aorta the proximal consecutive thrombus was in the femoral artery. In all of them it was slight in extent, appeared to have been formed terminally and could have had no effect on the outcome.

CASE No. 69 *Embolism of right axillary and brachial arteries.*

The autopsy specimen (Fig 6) shows an unattached thrombus with proximal and distal 'tail thrombi', lying in the axillary artery at the mouth of the subscapular. The brachial trunk is occluded by old decolorised thrombus at two points: (1) at the origin of the long branch (see below) and (2) at the elbow. (The decolorised thrombus is not well shown in the photograph but can be seen in the specimen, which has been preserved.) Both the specimen and the arteriograms (Figs 5 and 6) indicate that the embolus in the axillary artery did not completely occlude it

Note

The arteries in this case show a variation described by anatomists (see *Gray's Anatomy*, 29th Ed p 764) The *radial artery arises from the brachial trunk just above mid-humerus* In making the injection, the cannula has been inadvertently inserted into this radial branch instead of the brachial trunk, its position is indicated by the ligature seen in Fig 6

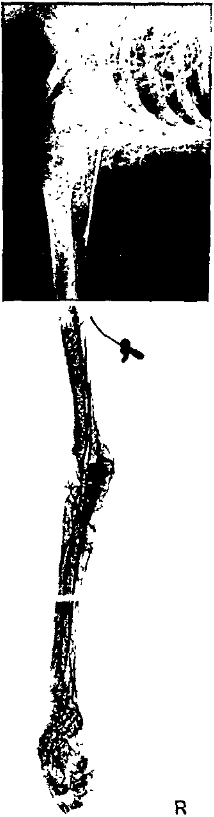


FIG 4 (*Case No. 69*)
Post-mortem arteriography of right upper limb.



Fig 5

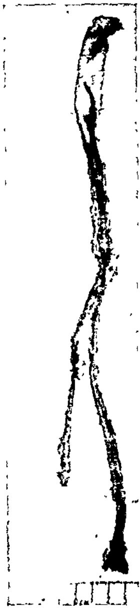


Fig 6

Fig 5 (*Case No 69*) Post-mortem arteriography of right upper limb Unreduced print

Fig 6 (*Case No 69*) Autopsy specimen Right axillo-brachial trunk.



CASE NO. 75. *Embolism of right ilio-femoral and left femoro-popliteal arteries*

The specimen (Figs. 8 and 9) shows occlusion of the right ilio-femoral trunk down to mid-thigh and in the arteriogram (Fig. 7) the whole of this occluded trunk is 'missing'. The superficial femoral and popliteal arteries below the occluded segment of the trunk are seen to be filled by collateral flow. On the left side the ilio-femoral trunk is patent to the lower end of the common femoral and has been visualised in the arteriogram but the superficial femoral, deep femoral and popliteal arteries, which are occluded, are 'missing' The specimen also shows that the occlusions consist partly of organised thrombus and partly of darker, more recent, 'intermediate' thrombus

FIG 7 (*Case No* 75)

Embolism of right ilio femoral and left femoro-popliteal arteries Post-mortem arteriography of lower limbs (injection into lower aorta)

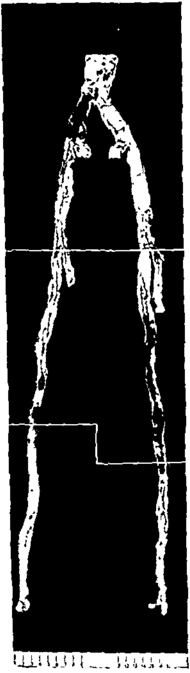


FIG 8

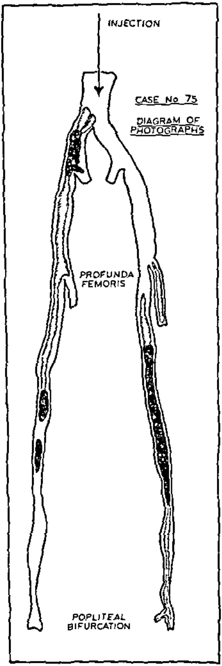


FIG 9

FIG 8 (*Case No* 75) Embolism of right ilio-femoral and left femoro-popliteal arteries. Autopsy specimen lower aorta and ilio-femoro-popliteal trunks

FIG. 9 (*Case No* 75) Embolism of right ilio-femoral and left femoro-popliteal arteries *Diagram of photograph shown in Fig 8*

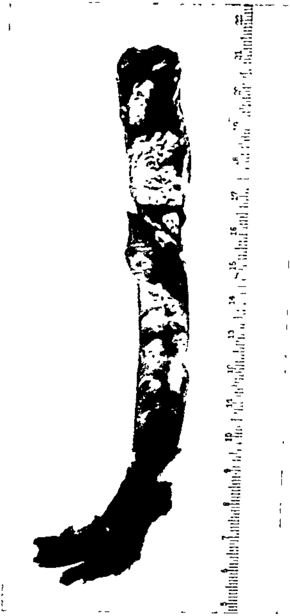


FIG 10 (*Case No 30*)

Embolism of aortic bifurcation Autopsy specimen, removed from lower aorta It consists of a 'Y'-shaped embolus which lay at the bifurcation, with a superimposed 'pillar thrombus'. The latter shows striation, suggesting deposition of successive layers from below upwards.

It can be concluded that proximal consecutive thrombosis is rarely of any importance in determining the outcome of an embolic occlusion.

2 Distal Consecutive Thrombosis

It is not easy to devise a satisfactory basis of comparison for the extent of distal consecutive thrombosis in different cases of limb embolism. A simple expression of its length is not necessarily a true indication of its possible effect in hampering collateral circulation For instance, in common femoral embolism a thrombus extending as far as the end of the superficial femoral artery might have a length of 20 cm but since the arterial trunk has relatively few branches in this part of its course its obliteration by consecutive thrombus would probably have little effect on collateral circulation In the case of an embolus occluding the bifurcation of the common iliac, a consecutive thrombus of shorter extent, say 15 cm, would block the mouth of the deep femoral and might therefore have more serious effects. In this discussion, distal consecutive thrombosis has been classified as 'major' in degree if it extends to and blocks both divisions of the next main bifurcation beyond the site of the embolus

e.g. In embolism of the mouth of the common iliac·	Extending to the bifurcation of the common iliac or further
In embolism of the bifurcation of the common iliac.	Extending to the bifurcation of the common femoral or further
In embolism of the bifurcation of the common femoral	Extending to the bifurcation of the popliteal or further

Consecutive thrombosis of lesser degree than this has been classified as 'minor'

According to this classification, the 64 limbs examined divided themselves as follows·

'Major' distal consecutive thrombosis	32 limbs
'Minor' or no distal consecutive thrombosis:	32 limbs

Using these two groups, the fate of the limb has been related to the extent of distal consecutive thrombosis. The terms used in recording the fate of the limb are defined as follows

Primary gangrene	Gangrene becoming evident within a few days of the onset of acute ischaemic symptoms and occurring while the general condition of the patient is relatively good.
Terminal gangrene	Gangrene appearing only after the patient has become moribund from other causes, in a limb which has shown good collateral circulation for at least 7 days.
Limb survival rate	Proportion of limbs surviving without gangrene, expressed as a percentage of the whole group.

(Further details of these definitions are given in Chapter VIII)

At first sight there appears to be some association between 'major' distal consecutive thrombosis and grave ischaemia. In the group with 'major' thrombosis, primary gangrene occurred in 11 of 32 limbs (34%), while in the group with 'minor' or no consecutive thrombosis primary gangrene occurred only in 3 of 32 limbs (9%). This difference is statistically significant (S.E. × 2 = 19·4). However, the comparison is not valid, for the group with 'major' thrombosis contains more of the serious forms of embolism (aortic, iliac and femoral) than the other group. If we exclude the less serious forms of embolism (brachial and popliteal), which rarely cause gangrene (Chapter VIII), the respective incidences of primary gangrene become 34% and 17%. This difference is not statistically significant (S.E × 2 = 24·2). The best comparison is between individual arteries rather than limbs and this is shown in Table 17. The numbers here compared are small but in the most numerous arterial category, comprising embolism of the aortic bifurcation and the mouth of the common iliac, taken together, the incidence of gangrene in the 'major' and 'minor' thrombosis groups is identical Comparison of the limb survival rates gives similar results Table 17 also shows that in 12 popliteal embolisms there was not a single example of 'major' consecutive thrombosis

TABLE 17

Extent of distal consecutive thrombosis related to fate of limb

Classified according to arterial site of embolism

Lower limbs only

Extent of distal consecutive thrombosis	Fate of limb	Site of embolism			
		Aorta or C iliac orifice Limbs	C. iliac division Limbs	Common femoral division Limbs	Popliteal division Limbs
'Major'	Survival	6	1	2	—
	Terminal gangrene	2	—	2	—
	Primary gangrene	8	1	—	—
	Totals	16	2	4	—
'Minor'	Survival	3	1	5	9
	Terminal gangrene	1	1	3	3
	Primary gangrene	4	—	—	—
	Totals	8	2	8	12

Consecutive thrombosis in upper limb embolism

Fifteen cases of upper limb embolism (5 axillary, 10 brachial) were examined at autopsy. Not a single example of 'major' consecutive thrombosis was found among them One case (axillary) developed gangrene which was probably terminal, though it was not long enough under observation to be formally so classified (Case No. 73) In two others (brachial), death ensued too soon for the fate of the limbs to be known (Cases Nos. 2 and 25)

Extensive consecutive thrombosis without gangrene

There were 7 examples of extensive distal consecutive thrombosis without gangrene in the affected limb (Cases Nos. 4, 10, 14, 29, 31, 69, 75 See Figs. 26, 27, 29, 31, 34, 35 in Appendix I). Two examples may be quoted. In Case 75, thrombus filled the whole of the right common iliac, external iliac and common femoral trunks and extended a little way into the superficial and deep femoral (Figs. 8, 9, 35). In Case 14 an embolus occluded the aortic bifurcation and consecutive thrombus filled both ilio-femoral trunks down to the bifurcations of the common femorals, also extending into the greater parts of both internal iliacs (Fig 27) This patient lived for 9 days after the onset of acute ischaemic symptoms and then died of cerebral embolism, the circulation in both lower limbs remaining good to the end

Massive primary gangrene without consecutive thrombosis

There were two examples of massive primary gangrene with little or no consecutive thrombosis In one, an embolus occluded the aortic bifurcation and the patient lived for 48 hours before dying with massive gangrene to the groins on both sides At autopsy, there was very little consecutive thrombus in the right common iliac and none in the left (Case No 25, Fig 28) In Case 76 there was an old-standing occlusion of the left external iliac artery New emboli lodged in the left common iliac, external iliac and internal iliac and the limb rapidly became gangrenous Following amputation, the patient lived for two months and then died of cerebral embolism At autopsy, no consecutive thrombus could be recognised in the arteries of the left lower limb (Fig 36)

3. Inter-embolic Thrombosis

When two emboli have lodged at different levels in the same limb, consecutive thrombosis may occur in the segment of arterial trunk enclosed between the two emboli There were 17 arterial trunks (in 15 patients) occluded by two or more separate emboli at different levels. In 9 of these arterial trunks consecutive thrombus was found completely filling the inter-embolic segment, in 2 trunks it filled some part of this segment and in the remaining 6 arterial trunks there was no inter-embolic thrombus at all. The findings give no grounds for concluding that inter-embolic thrombosis played any part in precipitating

gangrene. In the 4 patients who developed primary gangrene, the inter-embolic thrombosis was complete in one, incomplete in two and absent in one.

In certain cases, the character of the inter-embolic thrombus gave some indication as to whether it had formed soon after the embolic occlusion or considerably later There were 11 examples in which some assessment could be made. In 4 of them the inter-embolic thrombus appeared to have formed soon after lodgement of the emboli; in 7 it appeared to have formed much later.

These findings suggest that when an arterial trunk is occluded by two separate emboli, some circulation may be maintained in the intervening segment *through collateral branches leading into and out of it. This could explain why* in some instances there is no inter-embolic consecutive thrombosis. At some subsequent time, *perhaps through deterioration of the general circulation, this* local inter-embolic circulation may fail, with resultant thrombosis in the segregated arterial segment. There was no indication that this could precipitate gangrene

Conclusions

The results of this study of consecutive thrombosis do not support the commonly held view that it may be the deciding factor causing gangrene in an embolised limb. A number of facts are inconsistent with this theory

1. Consecutive thrombosis does not appear to precipitate gangrene in upper limbs, indeed, it seems rarely to occur there.
2. Extensive consecutive thrombosis sometimes occurs without precipitating gangrene.
3. Massive gangrene sometimes occurs in the absence of consecutive thrombosis.
4. If unbiased comparison be made, it is not possible to show any higher incidence of gangrene in embolic occlusions with major degrees of consecutive thrombosis than in those with minor degrees.

The extent and rapidity of formation of consecutive thrombus seem to be determined mainly by the extent of the 'segment of stagnation' in the occluded arterial *trunk and this latter is probably determined by the anatomical course* of the collateral circulation.

This conception can be illustrated by Case No. 14, in which there was an embolism of the aortic bifurcation and of the right common femoral bifurcation, probably occurring about the same time. *The patient survived for 9 days before* dying of cerebral embolism and up to that time there was no threat of gangrene in either lower limb. At autopsy, consecutive thrombus was found filling both ilio-common femoral trunks completely, as well as the greater parts of both internal iliacs. However, *it extended no further into the superficial femoral on* the right side (where there was also an embolism of the common femoral) than

on the left (Fig. 27). The anastomosing smaller branches of the iliac vessels must surely have taken part in the maintenance of this adequate collateral circulation; yet they could apparently do so without participation of the main iliac trunks themselves. These iliac trunks formed a 'segment of stagnation' and so became thrombosed without impairment of the collateral circulation.

VI

Clinical Features

SYMPTOMS

'Silent' embolism

During the past twenty years a number of observers have pointed out that the symptoms of limb embolism may sometimes be slight or even entirely absent (*e g* Fiolle (1936), Haimovici (1937)). Fiolle and Haimovici applied the term 'embolie occulte' to cases without any symptoms and 'embolie manquée' or 'embolie anischémique' to those which recovered spontaneously However, most observers have regarded both types as exceptional. Haimovici (1937) wrote that cases of 'embolie manquée' are '. . . infinitely less frequent than those with grave ischaemia, leading in the worst cases to gangrene'. In his later study (1950), he recorded 'silent' embolism in 17 out of a total of 300 occlusions but he localised 10 of these in small arteries such as the anterior tibial, posterior tibial and ulnar. In the same series he recorded 'anischaemic embolism' in 76 cases (25·3%)

In Chapter III was recorded the incidence of pulse deficiencies in the limbs of 269 patients with mitral stenosis who made no complaint of ischaemic symptoms (though in some of them questioning revealed a history of acute ischaemic symptoms in the past) Evidence of major arterial occlusion in one or more limbs was found in 51 of these patients but a history of past ischaemic symptoms could be elicited only in 26 (a further 7 patients gave a history of past cerebral embolism) Most of the pulse deficiencies were probably due to embolism with spontaneous recovery and in nearly half of them the embolism appears to have been 'silent'. In some of these latter there may well have been symptoms which the patient could not recall, but this itself suggests that they must have been very mild.

It seems unlikely that embolism could occur in a large arterial trunk such as the iliac without symptoms and most cases of silent embolism are in less important trunks such as the brachial, popliteal or deep femoral. Embolism of small arteries such as the tibial, radial or ulnar is probably silent in many cases and usually escapes clinical diagnosis. In the writer's material, excluding 'pseudo-embolism', there were 118 embolic incidents and these included 23 in which no history of any symptoms could be obtained. Twelve of them were

in the popliteal artery, 3 in the brachial and 1 in the deep femoral. There were 7 in larger arteries (5 iliac, 1 femoral, 1 axillary) but it is noteworthy that in 4 of these there had also been a cerebral embolism, possibly simultaneous, which must have obscured the symptoms of the limb embolism. Examination of the limb pulses in patients who have had cerebral embolism not uncommonly reveals signs of old peripheral embolism which has escaped attention in this way.

The relatively low incidence of upper limb embolism in most of the published series (Table 14) is further evidence of the occurrence of embolism with

TABLE 18

Mode of onset and severity of initial symptoms in limb embolism

85 incidents in which these data were recorded

Site of embolism	Number of cases	Mode of onset		Severity of initial symptoms			
		Sudden	Gradual	Mild	Moderate	Severe	'Shock'
Upper limbs							
Axillary	8	6	2	3	4	1	—
Brachial	9	8	1	5	3	1	—
Lower limbs							
Aorta	15	13	2	1	8	6	4
Iliac	18	17	1	1	3	14	2
Femoral	20	14	6	6	9	5	—
Popliteal	15	9	6	8	7	—	—
All sites	85	67	18	24	34	27	6

Summary of Table 18

33 *Aortic and iliac embolisms*	Onset sudden	30	(91%)
	Symptoms severe	20	(61%)
	'Shock'	6	(18%)
28 Femoral and axillary embolisms	Onset sudden	20	(71%)
	Symptoms severe	6	(21%)
	'Shock'.	—	—
24 Popliteal and brachial	Onset sudden	17	(71%)
	Symptoms severe	1	(4%)
	'Shock'	—	—

minor symptoms. Cerebral and lower limb embolism are common and it cannot be supposed that the upper limbs are really so much less subject to it. Because its symptoms are so often mild, upper limb embolism less often comes under observation (In Chapter V the same point was made about popliteal embolism)

It must be concluded that spontaneous recovery from limb embolism is relatively common and that cases with very slight or even absent symptoms are by no means rare.

Manner of onset and severity of initial symptoms

Traditional accounts of embolism of the limbs describe the onset of symptoms as sudden and dramatic but many observers have reported cases in which the onset was insidious and this has been re-emphasised by some of the more recently published general accounts (Haimovici (1950), Richards (1954)). The type of onset and degree of severity of initial symptoms in the clinical cases of this study are recorded in Table 18. The gradual type of onset occurred mainly in embolism of the small or medium-sized arteries but it was not unknown even in iliac and aortic embolism. The severity of the initial symptoms was graded directly in relation to the size of the artery occluded General symptoms resembling ' shock ' occurred only in embolism of the aorta or iliac arteries (see Table 18, also section on ' General symptoms ', later in this chapter).

Local symptoms

There is a record of some local symptoms in 99 of the 118 embolic incidents (' pseudo-embolism ' excluded). Table 19 shows the incidence of the various symptoms recorded.

Bearing in mind the fact that cases of embolism seen in hospital represent only a proportion of the whole, we see that pain is the commonest local symptom; it occurred in 70 of the 99 incidents with recorded symptoms, or 59% of all incidents. The pain was most commonly of ' distal ' type, localised to an area well beyond the site of the embolus. ' Arterial pain ', *i e.* pain near the site of impaction of the embolus was much less common.

' Distal pain ' alone:	58 incidents
' Distal pain ' plus ' arterial pain ':	11 incidents
' Arterial pain ' alone:	1 incident
Pain absent:	11 incidents
Inadequate information as to pain:	18 incidents
All incidents with symptoms recorded:	99 incidents

The pain ranged in severity from a mild aching (*e g.* Case No. 3) to a violent cramp-like pain, hardly endurable (*e g.* Case No. 7). ' Arterial pain ', when it

TABLE 19

Incidence of various local symptoms in 118 embolic incidents

(' Pseudo-embolism ' excluded)

Symptom	Number of incidents in which it was recorded	% of total
Pain	70	59%
Subjective cold feeling	45	38%
Numbness, ' dead feeling '	44	37%
Loss of power, weakness, ' heavy feeling '	20	17%
Tingling, ' pins and needles '	7	6%
Intermittent claudication	4	3%
Pallor of limb (noted by patient)	3	2·5%
Swelling of limb (noted by patient)	2	1·7%
Faintness (complained of by patient)	2	1·7%
Mental confusion	1	0·8%
No history of any symptoms	23	19%

Groups of symptoms appearing frequently in combination

(Mutually exclusive)

Symptoms	Incidents
Pain, Numbness	36 incidents
Pain, Numbness, Loss of power	10 incidents
Pain, Numbness, Coldness	26 incidents
Pain, Numbness, Coldness, Loss of power	7 incidents

occurred was always mild and transient In the 12 incidents with a record of ' arterial pain ', the embolic site was at the aortic bifurcation in 5, in the common iliac artery in 6 and in the axillary in 1. (The question of ' arterial pain ' and its significance is discussed in Chapter X.)

The other common local symptoms, in order of frequency, were subjective feeling of coldness, numbness or 'dead feeling', loss of power in the limb and tingling ('pins and needles'). There were no other local symptoms of any importance.

General symptoms

Apart from symptoms due to the causative heart disease, there are some cases of limb embolism who present general symptoms attributable to the embolism itself. Table 18 shows that a small number of cases, all examples either of aortic or common iliac embolism, had general symptoms described as 'shock'. These patients showed facial pallor, general prostration and in some cases sweating. The resemblance to surgical or traumatic shock, however, is only superficial. The pallor, sweating and general distress probably represent a reaction to severe pain. In contrast to patients suffering from true surgical shock, the blood-pressure of these cases tended to be *raised* above normal level during the early stages after onset. Table 20 records the blood-pressure readings in the 6 patients. In 4 of the 5 who were seen soon after onset (up to 5½ hours) the blood-pressure was somewhat above normal level. In the patient first seen 24 hours after onset the blood-pressure was low (Case No. 25).

TABLE 20

Arterial blood-pressure in cases of embolism showing general 'shock'

Case No.	Site of embolism	Time after onset	Arterial B P	Evidence of essential hypertension
1	Aorta	5 hours	190/130	None
8	L C I & R C I	5½ hours 11½ hours	190/100 180/105	None
25	Aorta	24 hours	90/?	None
50	Aorta	2½ hours 11½ hours	130/95 90/75	None
64	Aorta	3 hours	140/100	None
76	L C I.	? several hours	110/70	Present (clinical & P.M.)

Blood-pressure readings at an early stage after onset were recorded in a further 7 incidents in which the initial symptoms were classified as '*severe*', though not amounting to general 'shock'. In 6 of these the blood-pressure

was above normal level, though 2 had evidence of essential hypertension which may have accounted for it. In incidents with symptoms classified as 'mild' there are very few recorded data on this point.

A rise of general arterial blood-pressure following occlusion of a large artery was described many years ago (Katzenstein (1905)). It probably results from the sudden exclusion of an extensive arterial field from the general circulation, with consequent rise of relative blood volume. It may be succeeded in a few hours by a state of low pressure, especially in patients who are developing gangrene. It was observed only in embolism of the aorta and the iliac arteries.

In a patient with severe heart failure, this sudden rise of blood-pressure may cause aggravation of the failure and so produce the rapid general deterioration and death sometimes seen in aortic embolism (Case No. 64) When there is no heart failure, the increase of blood-pressure may well favour the establishment of collateral circulation and any form of treatment which may counteract it is to be avoided (Chapter XI)

Physical signs

The information on physical signs here given is based on incidents of limb embolism seen not more than 24 hours after the onset of acute ischaemic symptoms (for brevity, this is hereafter referred to as 'onset'). There were 42 such cases, comprising,

Aortic embolism:	8 incidents
Common iliac embolism	8 incidents
Common femoral embolism	6 incidents
Superficial femoral embolism·	1 incident
Popliteal embolism:	7 incidents
Axillary embolism:	4 incidents
Brachial embolism.	8 incidents
Total	42 incidents

Colour changes in the skin

Colour changes were recorded as pallor or cyanosis, either separately or in combination. They were present in the great majority of incidents seen within 24 hours of onset The changes observed at first examination were

Colour normal:	2 incidents
Pallor alone.	12 incidents
Cyanosis alone:	19 incidents
Pallor of part of limb, cyanosis elsewhere:	7 incidents
Information lacking	2 incidents
Total:	42 incidents

The two incidents in which the colour of the limb was normal were Case No. 60 (axillary, seen at 15 hours) and Case No. 79 (popliteal, seen at 8 hours).

(There were 10 further incidents, first seen 24–48 hours after onset and in 3 of these the colour of the limb was then normal.)

In most cases in which pallor was combined with cyanosis, the pallor was confined to the distal extremity of the limb, with a zone of cyanosis proximal to it. Pallor mottled with patches of cyanosis was seen in 4 incidents and this mottling extended to the digits in 3 of them. One case had a distal zone of extreme pallor with a more proximal zone of cyanotic mottling. Pallor of extreme degree, with a slightly yellow tinge and appearance of translucency of the tissues, is usually described as 'waxen pallor'; it indicates a high degree of bloodlessness. Pallor of this type, involving at least the whole of the foot, was seen in 7 incidents: 3 aortic and 4 common iliac. Waxen pallor and severe pallor with cyanotic mottling were seen only in cases with the most grave ischaemia (Chapter VIII—'Prognosis'). Some degree of cyanosis was seen more commonly than pallor

After an embolic occlusion there is a natural succession of colour changes in the skin, depending on the degree of improvement of the circulation. The immediate effect of the arterial occlusion is to produce pallor If collateral circulation is good, as it develops the pale area will acquire some colour, at first cyanotic while the circulation is sluggish, later tending towards the normal pink colour as circulation improves If collateral circulation be poor, cyanosis will be deep and persistent; if it be absent or almost absent, pronounced pallor will persist for a long period The cyanotic mottling already mentioned is of special interest. It gives the impression of a feeble circulation, supplied to the skin at isolated points by a fraction of the skin arterioles, the number being too few to provide uniform perfusion of the capillary network. In such a state, circulation is very little better than in the limb with waxen pallor

When necrosis occurs, a new colour change usually appears, due to extravasation of blood into the dead tissues This deep slate-blue colour cannot be blanched by pressure and is therefore easily distinguished from deep cyanosis. In profound ischaemia, the extremity of the limb may sometimes be so bloodless that extravasation staining cannot develop there and the foot, for example, may retain a waxen appearance, while a zone of extravasation staining appears more proximally. Ultimately the pale extremity may begin to darken with the development of mummification. Occasionally, chemical changes in the decomposing blood-pigments may engender a change in the colour of the extravasation staining from slate-blue to bright red (Case No. 9)

When early changes are compared with later developments, certain tendencies emerge and these are of some value for prognosis. The main point of interest is the duration of pallor in recovering limbs, as compared with limbs

destined to become gangrenous. There were 30 embolic incidents, involving 35 limbs, in which the first examination was made not more than 10 hours after onset. Twenty-one of these limbs survived and 10 developed primary gangrene; in 4 the result was indeterminate (this term is defined in Chapter VIII) Table 21 gives some indication of the duration of pallor (extending over the whole hand or foot) in surviving limbs and in limbs which later became gangrenous. It shows that in surviving limbs this sign was often seen up to 2 hours after onset (7 of 10 limbs) but not later (11 limbs). In non-surviving limbs, 6 out of 9 still showed pallor involving at least the whole hand or foot when examined more than 2 hours after onset. It would appear from this that in the great majority of limbs with adequate collateral circulation pallor does not persist for more than about 2 hours after onset (see also Chapter VIII).

Extravasation staining

Extravasation staining was observed in 30 embolic incidents. It never appeared less than 18 hours after onset and there were only 4 incidents in which it appeared within 36 hours There were 6 incidents in which the staining, when first observed, appeared as a few small patches only (less than 1 cm in diameter). In 4 of these the limb survived (in 2 with localised dermal necrosis which subsequently healed), in 2 there was massive gangrene In 8 incidents the staining appeared in large patches and in 16 it was confluent In all these 24 cases it heralded massive gangrene.

Objective coldness of the skin

Skin temperature measurements can be made with an electrical resistance thermometer, but for most clinical purposes palpation with the dorsal aspect of the examiner's fingers is quite adequate A difference of 1–1·5° C in the skin temperature of two limbs can usually be detected in this way Objective coldness of the skin was very similar in its incidence and usually almost identical in its extent to colour changes (pallor or cyanosis). In the 42 incidents, the sign was recorded as present in 39 (including the two with normal skin colour) and absent in one (In 3 incidents the record was deficient in this respect)

Objectively demonstrable muscular weakness

Examination for this sign was recorded in 35 of the 42 incidents. Some degree of impairment of power was found in 22 and power was normal in 13. When impaired, muscular power usually improved *pari passu* with the improvement of the ischaemic skin signs, sometimes very rapidly

The two incidents in which the colour of the limb was normal were Case No. 60 (axillary, seen at 15 hours) and Case No. 79 (popliteal, seen at 8 hours).

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Tendon reflexes

The condition of the tendon reflexes was recorded only in 8 incidents seen within 24 hours of onset (all lower limb occlusions). In 7 cases the tendon jerks were impaired or absent (most commonly the ankle jerks only) and in one they were normal (this case had only slight impairment of muscular power) The tendon reflexes usually returned when muscular power recovered, though often more slowly.

TABLE 21

Pallor of the whole hand or foot as a prognostic sign in embolism

30 incidents (35 limbs), all seen within 10 hours of onset

Duration of symptoms when examined	Subsequent fate of limb					
	Survival		Primary gangrene		Indeterminate	
	Number of limbs	Number with this sign	Number of limbs	Number with this sign	Number of limbs	Number with this sign
0–1 hr	7	5	–	–	1	1
1–2 hrs	3	2	1	1	2	1
0–2 hrs	10	7	1	1	3	2
2–5 hrs	7	–	7	5	–	–
5–10 hrs	4	–	2	1	1	–
2–10 hrs	11	–	9	6	1	–

Sensory impairment

Examination of cutaneous sensation was recorded in 29 of the 42 incidents. Some degree of objective sensory loss was found in 20 and sensation was normal in 9. Details, including the fate of the limbs, are condensed in Tables 22 and 23. Chief interest attaches to the relation between extensive and persistent sensory impairment and subsequent gangrene. From the data in Table 22 it appears that in aortic and iliac embolism

TABLE 22

Level of sensory impairment related to fate of limb

Aortic and common iliac embolism—11 incidents with adequate record
(All first examined within 24 hours of onset)

Case No	Site of embolism	Time after onset	Upper level of sensory impairment	Level on following day	Fate of limb
1	Aorta	5 hours	L groin	Unchanged	Gangr thigh
			R. mid-thigh	Unchanged	Gangr leg
4	Aorta	20 mins	L mid-leg	Lower	Survived
			R mid leg	Lower	Survived
14	Aorta	6½ hours	L nil	Nil	Survived
			R nil	Nil	Survived
50	Aorta	2½ hours	L nil*	Nil	Survived
			R knee	Unchanged	Gangr mid leg
7	R C I	1¾ hours	Knee	Lower	Survived†
8	L C I	5 hours	Knee	Unchanged	Gangr mid-leg
	R C I	5 hours	Mid-thigh	Sl lower	Gangr mid leg
29	L C I	2 hours	Nil	Nil	Survived
45	R C I	7½ hours	Mid-thigh	Unchanged	Gangr thigh
62	R C I	4 hours	Nil	Nil	Survived
65	L C I	8¾ hours	Toes only	Mid-foot	Survived

* This limb had survived C I embolism 16 months earlier

† This limb survived with severe ischaemic fibrosis after embolectomy.

TABLE 23

Level of sensory impairment related to fate of limb

Common femoral and popliteal embolism—9 incidents with adequate record
(All first examined within 24 hours of onset)

Case No	Site of embolism	Time after onset	Upper level of sensory impairment	Level on following day	Fate of limb
9	R C F.	22 hours	Toes (Slight)	?	Survived
20	R C F.	11½ hours	Mid-foot	Unchanged (extended later)	Gangr.: low leg
34	R C F	19 hours	Ankle	Lower	Survived
49	L C F	30 hours	Ankle	Lower	Survived
44	L P	12 hours	Nil	Nil	Survived
45	L P *	7½ hours	Mid-foot	Higher	Gangr · mid-leg (? terminal)
60	L P	12½ hours	Nil	Nil	Survived
74	L P	24 hours	Mid foot	?	Gangr low leg (? terminal)
79	L P	8 hours	Ankle	Lower	Survived

* This case also had partial occlusion of the L C I.

Six limbs which became gangrenous all had sensory impairment to the knee or higher, persisting more than 2 hours after onset.

In 9 limbs which survived 5 had no sensory impairment,
1 had impairment in toes only,
2* had impairment to mid-tibia,
1† had impairment to knee.

* 20 minutes after onset.
† 1¾ hours after onset

In these 9 surviving limbs, therefore, none had sensory impairment affecting as much as the whole foot and persisting more than 2 hours after onset. The two cases (3 limbs) who had sensory impairment extending above the ankle were both examined less than 2 hours after onset. In each case the level of sensory loss was recorded as 'lower' on the following day but the exact rate of regression is not recorded.

In common femoral and popliteal embolism (Table 23), none of the 9 limbs had sensory impairment extending above the ankle. Six of these limbs survived. Three limbs became gangrenous but in one of these the patient was moribund from other causes when gangrene developed (Case No 74) and in one other there was a partial occlusion of the common iliac as well as the occlusion of the popliteal (Case No. 45). The third case may have been adversely affected by inappropriate treatment (elevation of the limb. Case No 20).

Extensive and persistent sensory impairment, like persistent pallor, therefore appears to be a sign of considerable prognostic value (Chapter VIII)

Venous refilling sign

In arterial ischaemia of extreme degree, the superficial veins of the hand or foot may be invisible. When the ischaemia is less severe the veins are usually visible but if collateral circulation be poor they may appear only as dark threads, not raised above the surface In cases with better collateral circulation the veins may show some degree of fullness, though usually less than that of the normal limb (Nystrom (1936)). The venous circulation may be examined by noting the rate of refilling from the periphery after emptying a vein by expression.

Richards (1954) discussed this sign and pointed out that after the lapse of some hours the superficial veins may become over-filled, probably as a result of thrombosis of the main deep veins of the limb However, in cases of embolism examined relatively soon after onset, the sign was found to be of some value in assessing the degree of ischaemia The test was made in 21 embolic incidents. The result of the test is rather difficult to classify precisely but there were 14 incidents in which the rate of refilling of the vein was recorded as ' negligible ' or ' sluggish ' and primary gangrene ensued in 8 of these In 6 examples classified as ' fairly good ' or ' normal ' the limb survived in every case.

Arterial pulses

The ' cardinal sign ' of arterial embolism is absence of the palpable arterial pulses distal to the occlusion. This sign is not invariable and some pulsation may persist beyond the embolus in certain conditions:

1 Pulsation in a large artery, *e g* the iliac, may sometimes be transmitted through an occluding embolus so that it is felt for some distance beyond the occlusion ('Nordentoft's sign '). This probably occurs when the occluding embolus is a soft, very recently formed thrombus (Chapter V —' Character of embolic thrombi ') It usually disappears within a couple of days.
2. An embolus may sometimes not occlude the artery completely—presumably when it lies astride an arterial bifurcation, occluding one division completely and the other partially.

3. In cases with very good collateral circulation, a weak pulse may sometimes be transmitted through the collateral vessels to the main trunk beyond the embolus.

Even when pulsation persists beyond an embolic occlusion, it will almost invariably be weakened as compared with the normal limb. It is important to take these facts into consideration in diagnosis, for correct localisation of the site of an embolus depends more upon its effects on arterial pulsation than on any other evidence. In determination of the site of an embolus, therefore, *weakened* pulsation usually has the same significance as *absent* pulsation (Chapter VII) Many authors have suggested that pulsation proximal to an embolus may often be weakened by spasmodic contraction of the occluded artery. In the writer's experience this is rare (Chapter X)

There were 66 embolic occlusions seen within 7 days of onset (' pseudo-embolism ' excluded). Among these there were 13 in which at the initial

TABLE 24

Persistence of pulsation distal to an embolic occlusion

Time of diagnosis and site of embolism
66 incidents, all seen within 7 days of onset

Time after onset	Total number of incidents	Incidents with persistent pulsation	
		Site of embolism	Number
0–10 hours	30	Aorta	2
		Common iliac	4
		Axillary	1
		Brachial	1
		All sites	8
10–24 hours	14	Aorta	2
		Common femoral	1
		Axillary	1
		All sites	4
24–48 hours	10	—	—
2–7 days	12	Common iliac	1
0–7 days	66	All sites	13

TABLE 25

Persistence of pulsation distal to an embolic occlusion

12 examples, all seen within 24 hours of onset

Case No.	Site of *embolism*	Pulses present at first examination		Pulses *suppressed*	? Later disappearance of pulses	Fate of limbs
		Artery	Volume			
6	Aorta	R fem L fem	Good Weak	R & L pop All foot p	Both within 24 hours	L P G * R P G
11	R axill †	R brach R rad	Weak Weak	— —	Both within 5–11 days	Survival
14	Aorta	R fem L fem L pop	Good Good Good	R pop All foot p	All in 9 days (6 hours before death)	L Survival R Survival
15	Aorta†	L fem. L pop R fem R pop	Good Good Weak Weak	All foot p	Pres at 17 days Absent at 18 *months*	L Survival R Survival
34	L C I.†	L ex I	Weak	L fem L pop All foot p	Pres at 3 days L fem palp at 7 days	P G to ankle
39	L brach	L rad	Weak	—	In 4 days	Survival
45	R C I	R fem	Weak	R pop R foot p	In 48 hours	P G to thigh
49	L C F †	L pop	Weak	L foot p	In 3 days	Survival
54	L axill †	L brach (upper)	Weak	L lr brach L rad L ulnar	In 2 days	P G mid-radius
64	Aorta	L fem R fem	Weak Weak	L pop L foot p R pop R foot p	— —	Indeterminate (Died at 4½ hours)
65	L C I †	L fem.	Weak	L pop L foot p	In 24 hours	Survival
76	L.C I	L fem	Weak	L pop L foot p	Pres at 2 months	P G. to mid-leg

* P G —Primary gangrene

† Site not anatomically verified but clinically very probable

3. In cases with very good collateral circulation, a weak pulse may sometimes be transmitted through the collateral vessels to the main trunk beyond the embolus.

Even when pulsation persists beyond an embolic occlusion, it will almost invariably be weakened as compared with the normal limb. It is important to take these facts into consideration in diagnosis, for correct localisation of the site of an embolus depends more upon its effects on arterial pulsation than on any other evidence. In determination of the site of an embolus, therefore, *weakened* pulsation usually has the same significance as *absent* pulsation (Chapter VII). Many authors have suggested that pulsation proximal to an embolus may often be weakened by spasmodic contraction of the occluded artery. In the writer's experience this is rare (Chapter X).

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		Common iliac	4
		Axillary	1
		Brachial	1
		All sites	8
10–24 hours	14	Aorta	2
		Common femoral	1
		Axillary	1
		All sites	4
24–48 hours	10	—	—
2–7 days	12	Common iliac	1
0–7 days	66	All sites	13

these patients suffered from renal damage and biochemical disturbance, especially potassium imbalance. Guthkelch (1943) reported a case of this type following

TABLE 26

17 embolic incidents with local signs of ischaemic muscle damage

Case No.	Site of embolism	Fate of limb	Grade of muscle damage	Duration of acute muscle signs	Final result of muscle damage
7	R C I.	Survival	Severe	2 weeks	*Contracture*
8	L C I R C I	Gangrene Gangrene	Severe Severe	Indeterminate (amputation) Indeterminate (amputation)	Indeterminate Indeterminate
20	R C.F	Gangrene	Moderate	8 days (to amputation)	Indeterminate
21	R C I	Gangrene	Moderate	2 weeks (amputation at 32 days)	Indeterminate
34	L C I	Gangrene	Moderate	9 days (to death)	Indeterminate
44	L pop	Survival	Slight	6 days	Recovery
46	L S F	Gangrene	Slight	22 days (to death)	Indeterminate
50	Aorta	Gangrene	Moderate	3 days (to amputation)	Indeterminate
62	R C I	Survival	Moderate	2 weeks	Recovery
65	L C I	Survival	Slight	7 days	Recovery
68	R brach	Survival	Slight	2 weeks	(slight wasting) Recovery
69	R axill	Survival	Severe	3 months (to death)	*Contracture*
70	R axill	Survival	Slight	10 days	Recovery
73	R axill	Gangrene (terminal)	Severe	3 days (to death)	Indeterminate
78	R S F.	Survival	Slight	2 weeks	Recovery
81	Aorta	Gangrene	Moderate	2 weeks	Indeterminate

examination pulsation was noted in the arterial trunk distal to the site of the embolus. (In 7 of these the actual site of the embolus was subsequently verified at autopsy. In the other 6 the site was established with reasonable certainty by the course of events after the acute ischaemic phase.) The time of diagnosis and sites of embolism in these 13 incidents are shown in Table 24. Twelve of the incidents (involving 15 limbs) were seen within 24 hours of onset and the details of these have been condensed in Table 25. The following facts emerge:

1. Ten of the 12 occlusions (in Table 25) were in large arteries in or near the torso (4 aortic, 4 common iliac, 2 axillary).
2. In 2 cases there was persistent pulsation for a very considerable distance beyond the site of the embolus (Cases 14 and 15, both aortic, one anatomically verified)
3. The distal pulses initially palpable were of good volume only in 4 of 15 limbs; in all the others they were obviously weakened.
4. In 7 limbs the distal pulses initially palpable subsequently disappeared—in 3 limbs within 24 hours, in 2 limbs within 48 hours and in 2 limbs within 5 days. In 6 limbs the distal pulses persisted for periods from 7 days to 2 months.
5. In most cases in which some distal pulses persisted there were others, more distally, which were suppressed
6. In some cases with early disappearance of the post-embolic distal pulses the limb survived, in some with more prolonged persistence of distal pulses the limb became gangrenous.

Persistence of distal pulses is therefore not uncommon; it may be a pitfall in localisation and it is of no assistance in prognosis. (See also Chapter VII—'Diagnosis of the site of an embolus' and 'Problems of clinical diagnosis')

Ischaemic muscle damage

Ischaemic muscle damage following limb embolism was described by Chvostek (1892) and Langer (1895), both of whom reported typical cases and recognised their similarity to the traumatic ischaemic contracture first described by v. Volkmann (1881). Many subsequent writers have described the deep swelling and tenderness in muscles which sometime occur in the acute ischaemic phase, followed in a proportion of cases by fibrotic contracture (Doberauer(1907), Brooks (1922), Leriche and Policard (1920b), Lohr (1927), Bernard (1930), Jefferson (1934), Griffiths (1938)). Nevertheless, in general accounts of the clinical features of limb embolism the subject usually receives less attention than it merits.

During the Second World War, interest was aroused in the general syndrome caused by extensive ischaemic muscle damage in air-raid casualties whose limbs had been subjected to prolonged pressure under fallen masonry. Many of

was tested for myohaemoglobin, usually repeatedly In 5 cases all tests were negative and these included the most severe of all examples of ischaemic muscle damage (Case No. 7, already described). One case of simultaneous embolism of both common iliac arteries (and probably also both femorals), with signs of severe ischaemic muscle damage in both limbs, gave two positive urine tests for myohaemoglobin, both on the third day after onset. A third test, made on the 10th day, was negative. This patient also had a slight rise of serum urea (70 mgm per 100 ml, on the 8th day after onset) Estimations of serum potassium level were made on two of the patients (including Case No. 7) and both gave normal results.

embolism of the femoral artery and Bywaters and Stead (1945) reported biochemical studies on a similar case following thrombosis of the femoral artery. The two latter authors suggested that biochemical disturbance of this kind might be responsible for death in some cases of embolism.

Excluding 'pseudo-embolism', there were 71 embolic incidents seen within 14 days of onset. Among these there were 17 incidents with a record of local signs of ischaemic muscle damage. The signs ranged in severity from slight local tenderness and induration of the muscles, rapidly subsiding, to extreme general swelling and tension of the whole limb, followed by fibrotic contracture. The details are condensed in Table 26. (Some of the limbs became gangrenous. In such cases, ischaemic muscle damage was recorded as present only when it occurred in the surviving part of the limb, proximal to the demarcation line.)

Signs of ischaemic muscle damage occurred mainly in occlusions of the larger arteries (aorta: 2, common iliac: 7, femoral: 3, axillary: 3, popliteal: 1, brachial: 1) In 8 limbs with sufficient survival time for assessment, recovery of the muscles was recorded in 6 and fibrotic contracture resulted in 2. In limbs which recovered, the acute muscle signs (tenderness, induration or swelling) usually subsided within two weeks

The most severe example of ischaemic muscle damage in a surviving limb occurred in a woman of 44 years with embolism of the common iliac artery, in whom successful embolectomy was performed about 4 hours after onset Within a few hours of operation, the whole limb was extremely tense, painful and swollen and the final result was permanent paralysis and fibrosis of most of the muscles below the knee. *It seems possible that the restoration by embolectomy* of a free blood-flow into the damaged muscles may have been a factor in the production of such severe fluid exudation into them (Case No 7). Griffiths (1938) described three cases of ischaemic contracture following limb embolism and it is noteworthy that all three were treated by embolectomy. The writer's material includes 75 examples of recovery from an embolic occlusion without operative treatment and only in one of these did fibrotic contracture result. (In addition to this clinical series, the examination of patients with mitral stenosis disclosed 71 spontaneously recovered arterial occlusions without a single example of contracture.)

(In addition to the 69 patients with limb embolism, Appendix II contains records of a further 12 patients who had acute non-embolic arterial occlusions. Three of these had local signs of ischaemic muscle damage (Cases Nos. 33, 35, 40))

Biochemical tests

Biochemical tests were made only in 6 cases of limb embolism. These cases all had signs of ischaemic muscle damage and in each of them the urine

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2. Thrombo-phlebitis with arteriospasm

During the course of this study, in addition to the clinical series of embolisms, a considerable number of acute ischaemic syndromes due to other causes were seen. Only one convincing case of thrombo-phlebitic arteriospasm was recognised (Case No. 57). In this case there was no heart disease and the acute ischaemic syndrome was preceded by two separate incidents of pulmonary embolism, which helped to establish the diagnosis of deep vein thrombosis. The popliteal and both foot pulses, all of which had been recorded as present three days previously, were suppressed for three days. The ischaemic signs were mild and even if the case had been wrongly diagnosed as embolism, operation would not have been contemplated

In most of the cases of thrombo-phlebitic arteriospasm described in the literature, the ischaemic signs have also been relatively mild (see references in Chapter X—'Introduction') This condition is therefore not of great importance as a source of diagnostic error. The rule already stressed—that embolism should not be diagnosed in the absence of heart disease—will usually prevent the erroneous diagnosis of embolism.

3. 'Pseudo-embolism'

Many observers have described cases of acute ischaemic syndrome, coming on suddenly and presenting all the features of embolism, including suppression of pulses, yet subsiding completely in a short time, with return of the absent pulses (Audier (1937), Atlas (1942), Learmonth (1948), Leriche (1947)). This phenomenon has been discussed, among others, by Haimovici (1937), Leriche (1947), Pickering (1951) and Richards (1954) It has usually been attributed to arterial spasm of obscure causation, yet pseudo-embolism occurs almost exclusively in patients who have heart disease of the type liable to produce embolism. Leriche, however, described instances occurring in thrombo-angeitis obliterans and in 'senile arteritis'.

A certain amount of confusion attaches to the term 'pseudo-embolism'. Some writers have used it to describe any transient acute ischaemic syndrome with rapid and complete recovery, observed clinically without any anatomical examination Others have applied the term to cases in which operative exploration has failed to reveal an expected embolus. Strictly speaking, the term should be reserved for the condition in which ' all the features of embolism except the embolus are present' (Richards (1954)). In order to be sure that these conditions are fulfilled, a full anatomical examination of the arteries concerned is essential. Such an examination is impossible in the conditions of an operative exploration, it can be made only subsequently at autopsy. It is not mere pedantry to insist on this, for in the writer's material some examples of true embolic occlusion were observed in which the ischaemic syndrome was of very brief duration (see below) Pickering (1951) pointed out that some cases of

VII

Diagnosis

DIFFERENTIAL DIAGNOSIS

A CLINICAL picture of acute ischaemic syndrome resembling limb embolism is produced by relatively few other causes. For purposes of clinical diagnosis they may be reduced to three:

1. Local arterial thrombosis.
2. Acute arterial spasm—particularly that sometimes associated with thrombophlebitis of the deep veins.
3. ' Pseudo-embolism '.

1. Local arterial thrombosis

Though occasionally caused by rare forms of arteritis (*e.g.* Case No. 18), local arterial thrombosis is usually due to arteriosclerotic intimal disease. It is rarely possible to recognise a localised arterial lesion, confined to the site of the occlusion, and in most cases the only relevant evidence is the presence of general arterial disease. However, it is not possible to exclude embolism as a cause of the ischaemic syndrome on the grounds either of the age of the patient or the presence of general peripheral arteriosclerosis. Sixty-three embolic incidents were recorded in patients over 60 years of age, the embolic character of the occlusions being established in the majority by good anatomical evidence. Many of these elderly cases had extensive peripheral arteriosclerosis and in some cases this led to an erroneous conclusion that the arterial closure was not due to embolism (*e.g* in Case No. 67). In practice, the distinction can be made only by the presence or absence of ' emboligenic ' heart disease, i.e. mitral stenosis, auricular fibrillation, bacterial endocarditis or myocardial infarction. Any acute ischaemic syndrome occurring in the presence of heart disease of this group must be presumed to be embolic, for there is no way of proving that it is not, except perhaps by arteriography, which can rarely be performed quickly enough. Treatment should therefore be guided by the presumption that the occlusion is embolic.

Conversely, a diagnosis of embolism is rarely justified in the absence of heart disease. Only one embolic occlusion out of the series of 118 occurred in a patient whose heart was normal (Chapter IV).

2. Thrombo-phlebitis with arteriospasm

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TABLE 27

12 examples of transient acute ischaemic syndrome

Case No	Site	Grade of ischaemic symptoms	Duration of ischaemic symptoms	? Return of pulses	Designation	? Other embolic incident	Remarks
7	L C I.	Moderate	3 hours	Yes 3 hours	Migrating embolus	Yes	Further similar incident 1 year later 2 years later, all limb pulses absent
7	L C I.	Moderate	2 days	Yes 3 days	Pseudo-E ? cause	Yes	
7	L C.I	Moderate	2 days	Yes 4 days	Pseudo-E ? cause	Yes	
12	R Brach	Mild	7 days	No	True E.	No	Confirmed by autopsy
15	Aorta	Moderate	4 days	No*	? True E	No	No autopsy
16	R Axill	Moderate	6 days	Yes 21 days	Pseudo-E ? cause	No	Controlled by autopsy
21	L C I	Mild	some hours	Yes some days	Migrating embolus	Yes	Patient survives
59	L Axill	Mild	2 days	No 35 days	Pseudo-E	Yes	Autopsy syphilitic arteritis
60	L Axill.	Moderate	7 days	Yes 11 days	? True E	Yes	No autopsy
65	R C I	Severe	10 min	Yes 8 hours	Migrating embolus	Yes	Patient survives
75	R Brach	Moderate	2 days	Yes 3 days	True E	Yes	Confirmed by autopsy
77	R Brach	Moderate	½ hour	Yes ½ hour	Migrating embolus	Yes	Patient survives

* Still absent 18 months later.

transient acute ischaemic syndrome may be explained by embolic migration; he described an instance of embolism of the femoral artery with very transient ischaemic symptoms, which were later explained at autopsy by the discovery that the embolus had moved into the deep femoral.

In the present study there were 12 examples of transient acute ischaemic syndrome in 10 patients, all with heart disease. Seven of these patients also had other incidents of proved or probable limb embolism. The clinical details have been condensed in Table 27.

These 12 transient acute ischaemic syndromes can be classified as follows:

'Pseudo-embolism', controlled by autopsy	2 incidents
'Pseudo-embolism' not anatomically controlled	2 incidents
Migrating embolus.	4 incidents
True embolic occlusion, confirmed by autopsy:	2 incidents
Probable embolic occlusion, not so confirmed.	2 incidents

The first fact to be emphasised, therefore, is that certain cases of proved embolic occlusion produce extremely transient ischaemic symptoms, with early return of the suppressed pulses. In one example, an embolism of the brachial artery produced ischaemic symptoms lasting only 2 days and the radial pulse returned in 3 days (Case No. 75). At least one case of pseudo-embolism caused ischaemic symptoms and suppression of pulses for considerably longer than this (Case No. 16). Classification of a case of transient ischaemic syndrome as pseudo-embolism must therefore be only presumptive until it has been proved by a full examination of the arteries that there is no occluding embolus.

Secondly, as Pickering (1951) has pointed out, migrating embolus can produce a transient ischaemic syndrome clinically resembling pseudo-embolism, though in most cases it is of briefer duration. There were 3 (possibly 4) examples of this in the series. In all cases the embolus seems to have lodged temporarily at the aortic bifurcation, with ischaemic symptoms in both lower limbs. The symptoms in one limb subsided rapidly when the embolus moved into the common iliac artery of the other. These cases do not usually pose any very difficult diagnostic problem unless the migration is into a 'silent' trunk such as the internal iliac or deep femoral (as in Pickering's case), where the embolus will leave no effects to indicate its presence.

Thirdly, there remain some cases, properly termed 'pseudo-embolism', showing 'all the features of embolism except the embolus'. The best example was in a woman of 58 years who had a myocardial infarction. Nine days later she had an acute ischaemic syndrome in the right upper limb. At examination, 3 hours after onset, the ischaemic signs were of moderate severity and the brachial and radial pulses were absent, a diagnosis of axillary embolism was therefore made. The ischaemic signs rapidly subsided and had disappeared 6 days later but the brachial and radial pulses did not return for 21 days. Five months later the patient died of a new myocardial infarction and at autopsy a very careful examination was made of the innominate, right subclavian, right axillary and right brachial arteries and all their branches. No old thrombus was

found and there was no macroscopically visible disease of the arterial wall. *Old* mural thrombus was found in the left ventricle (Case No. 16). This case fully satisfies the requirements for the definition of pseudo-embolism; moreover, the patient also had emboligenic heart disease The acute ischaemic syndrome was *presumably caused by* spasm *of the arterial trunk,* though no local mural lesion was found which might have caused it. Any such lesion might, of course, have healed in the interval of 5 months which elapsed before autopsy.

In another example of pseudo-embolism (Case No. 59) there were mural lesions, for there was a syphilitic arteritis of the affected artery. By a coincidence, this patient also had rheumatic heart disease. In Case No 7 there was embolism of the right common iliac, with transient ischaemic signs in the left lower limb also, probably due to migration of an embolus from aorta to right common iliac. Subsequently this patient had two separate transient ischaemic episodes affecting the left common iliac artery. In both the limb pulses were temporarily suppressed but returned in 3 to 4 days. There was another attack of ischaemic symptoms a year later but this was not observed. When the patient was examined after a further year the pulses were absent and they never again returned (this patient was still surviving at the time of this report).

Case No. 77 was of exceptional interest, for the acute ischaemic signs in an upper limb, which appeared simultaneously with a cerebral embolism, suddenly resolved while the brachial artery was being palpated. The radial pulse reappeared immediately and there was a reactive hyperaemic flush in the hand. It seems improbable that arterial spasm due to a mural lesion could resolve so suddenly and the most acceptable explanation of this observation is embolic migration, perhaps assisted by palpation of the arterial trunk.

Of the 4 incidents classified as pseudo-embolism, 2 affected the common iliac artery and 2 the axillary Many of the examples reported in the literature have also affected the larger arteries.

Pseudo-embolism is further discussed in Chapter X *and we are here con*cerned only with the diagnostic problem The main risk would seem to be that of regarding an embolic occlusion of the aortic bifurcation as a possible pseudo-embolism and so delaying operative exploration. This risk is a real one, for in some cases *of aortic embolism the ischaemic signs are not very severe* in the early stages but deterioration occurs and gangrene ensues (Chapter VIII—'Prognosis'). Pseudo-embolism is rare in comparison with true embolic occlusion and an acute ischaemic syndrome in a patient with heart disease should therefore be regarded as embolic. This attitude may occasionally lead to an unnecessary operative exploration but this risk is less serious than that of temporising in a case of aortic embolism.

In ischaemic syndromes affecting the brachial or the popliteal artery the distinction is not important, for operation should not usually be contemplated. In occlusions of the axillary, common iliac or common femoral arteries, the

TABLE 28

15 errors of localisation of site of an embolus

Case No	Actual site	Duration of symptoms	Site diagnosed	Classification of error		Cause of error and comment
				Siting error	Gravity of error	
6	Aorta	13 hours	R. & L femoral	Distal	Major	Persistence of femoral pulses
7	R C I	$1\frac{3}{4}$ hours	Aorta	Prox	Minor	Migration
8	R. & L C I	5 hours	Aorta	Prox	Minor	? Migration Not distinguishable
14	Aorta	6 hours	R C.F & L P	Distal	Major	Persistence of both femoral and one popliteal pulse
22	Aorta	30 hours	L C I & R P	Distal	Major	Persistence of R F. and R P pulses
37	L S F	2 weeks	L C F	Prox	Minor	Probability. Not distinguishable
45	L P * (upper)	$7\frac{1}{2}$ hours	L C F	Prox.	Minor	Pop pulse suppressed Not distinguishable
46	L S F	7 days	L C F	Prox	Minor	Probability Not distinguishable
47	Aorta	30 hours	R C I & L C F	Distal	Major	Persistence of L femoral pulse
48	L P (upper)	$5\frac{1}{2}$ hours	L F	Prox	Minor	Pop pulse suppressed Not distinguishable
50	Aorta	$2\frac{1}{2}$ hours	R C I	Distal	Major	Old embol L C I Minimal ischaemic signs on L side
67	R C I	?	R C F †	Distal	Major	Persistence of R femoral pulse
67	L C I	? days	L C F	Distal	Major	Persistence of L femoral pulse
78	L P	3 days	L C I	Prox	Major	Suppression of proximal pulses ? arterial spasm
78	R S F	3 hours	R C F	Prox	Minor	Probability Not distinguishable

* Also had partial occlusion of L C I

† Error made by another observer Repeated with L C I by writer

decision whether to operate should be governed by the intensity of the ischaemic signs (Chapters VIII and XII).

Diagnosis of the site of an embolus

In a total of 74 embolic occlusions, all diagnosed not more than 3 weeks after onset, errors of localisation of the site of the embolus were made on 15 occasions. Details of the individual errors are condensed in Table 28

These errors of localisation can be classified in two different ways:

1. *With respect to localisation*
   (a) 'Distal error'—the embolus being thought to lie more distally than it actually does.
   (b) 'Proximal error'—the embolus being thought to lie more proximally than it actually does
2. *With respect to clinical importance*
   (a) 'Major error'—having an effect of some importance on clinical assessment and management
   (b) 'Minor error'—having no importance for clinical assessment or management

Reference to Table 28 will show that there were 8 proximal errors and 7 distal errors. However, 7 of the 8 proximal errors were of minor type One of them was probably explained by embolic migration (Case No 7) and 6 were occasioned by 'working to rule' and assuming that the embolus lay at the nearest main bifurcation above the suppressed pulses, for example at the common femoral bifurcation when in fact it lay in the superficial femoral. An error of this type is hardly to be avoided except by arteriography and it is of no great consequence in clinical management. The only proximal error which could be called a major error was that in Case No 78. This was an embolism of the popliteal bifurcation, complicated by arterial spasm which caused suppression of the popliteal and femoral pulses and so led to an erroneous diagnosis of iliac embolism In the writer's experience this phenomenon is rare (Chapter X).

In contrast to the proximal errors, every one of the distal errors was a major error. The distal errors comprised 5 cases of aortic embolism and 2 of common iliac embolism, all wrongly diagnosed as more distally placed occlusions. Six of these 7 errors were due to persistence of one or more distal pulses (this has already been discussed in Chapter VI). The remaining distal error was the most serious diagnostic error of the whole study. Case No. 50 had embolism of the left common iliac artery and made an excellent recovery. Sixteen months later she had embolism of the aortic bifurcation. This produced very grave ischaemic signs in the right limb, but those in the previously embolised left limb were quite trivial. Because of this, and because of the known absence of pulses in the left limb since the earlier occlusion, it was wrongly concluded

that the new embolism was in the right common iliac. (This case is further discussed in Chapter X—Section (*d*).)

Problems of clinical diagnosis

The most difficult diagnostic problem is the recognition of aortic or common iliac embolism and, in particular, the distinction between aortic embolism and simultaneous separate embolism of the two lower limbs. The chief source of difficulty is persistence of distal pulses, which is not uncommon. Three guiding principles must be emphasised:

1 Embolism of the aorta is somewhat more common than simultaneous embolism of the two lower limbs (in this series, 17 instances of the former to 8 or 9 of the latter. In a doubtful case, therefore, probability will favour a diagnosis of aortic embolism

2 In deciding the site of an embolus, a *weakened* pulse has the same significance as an *absent* pulse This principle is the most important guide in diagnosis Its application will prove misleading only in the event of proximal spasm of the arterial trunk and in the writer's experience this is a rare phenomenon (Chapter X)

3. In aortic embolism the prognosis is so bad and the indication for operation so urgent that it is better to risk an unnecessary operation than to incur delay.

'Relapsing ischaemic syndrome'

Several patients were seen who presented with a typical acute ischaemic syndrome, having all the appearance of a very recent embolic occlusion. However, when the artery was examined shortly afterwards, either at operation or at autopsy, an occlusion was found which from the appearance of the thrombus and its state of adhesion appeared to have been present far longer than the duration of the ischaemic symptoms (Cases Nos 5, 23, 30, 46)

Case No. 30 was a woman of 73 years, admitted to hospital for congestive heart failure She had auricular fibrillation, which was known to have been present for at least three months, but no record of the limb pulses was made at the time of admission Five weeks after admission her general condition suddenly became very poor and she developed severe acute ischaemic signs in both lower limbs. All the lower limb pulses were found to be absent and a diagnosis of recent embolism of the aortic bifurcation was made. Gangrene ensued in both legs and the patient died 4 days after onset of the ischaemic symptoms. At autopsy, a firm 'Y' thrombus of relatively old appearance, probably an embolus, was found at the aortic bifurcation, with more recent soft thrombus filling the arterial trunks of both limbs as far as the popliteals. The embolus was surmounted by a firm 'pillar thrombus' with a rounded, unattached upper end; this had a series of transverse striations which suggested that it had been formed by a process of gradual accretion from below (see Figs. 10 and 30, also account of proximal consecutive thrombosis in Chapter V)

If this interpretation is correct, the embolus must have been present at the aortic bifurcation for at least several weeks and there was therefore an adequate collateral circulation for this period. A failure of the collateral circulation, probably precipitated by cardiac deterioration and consequent fall of blood-pressure, had caused the acute ischaemic syndrome which culminated in massive gangrene of the legs.

The other three cases of this group were in most respects similar to Case 30. There were records of three further similar cases, all due to old-standing arterial occlusions of non-embolic type (Cases Nos. 35, 43, 71).

Some cases of embolism were observed during the initial acute ischaemic phase and the period of spontaneous recovery. Subsequently the general condition of these patients deteriorated and the collateral circulation then failed, gangrene of ' terminal ' type resulting. Case No. 9 had embolism of the right common femoral artery, due to bacterial endocarditis. Collateral circulation was good and the limb survived well for 7 days, but the general circulation then deteriorated and the foot became gangrenous shortly before death. Case No. 52 was an even more striking example. A woman of 28 years, suffering from subacute bacterial endocarditis, had embolisms of the right common femoral and left external iliac arteries, with unassisted recovery in both limbs. Six months later she had an embolism of the aortic bifurcation, which produced severe acute ischaemic symptoms, but these also subsided and she was even able to walk a little for two weeks. After this the advancing heart disease caused general deterioration and fall of blood-pressure, whereupon the ischaemic signs reappeared and bilateral gangrene ensued. A number of other similar cases were observed, and most of them have been classified as examples of ' terminal gangrene ' (defined in Chapter VIII).

The term ' relapsing ischaemic syndrome ' (or ' delayed ischaemic syndrome ') has been applied to cases of this type Their chief clinical importance lies in the fact that if their earlier history is not known it is easy to mistake them for recent embolic occlusions and even to subject them to futile operations, as was done in one of the writer's cases (Case No. 23). The poor general condition which is responsible for precipitating the relapse of ischaemia may be misinterpreted as a condition of ' shock ' resulting from an embolism. Operation on such a case will merely hasten the inevitable end

Diagnostic errors of this kind may sometimes be avoided by recognising that spontaneous recovery from embolism is not uncommon, and by regularly examining the limb pulses and recording any deficiencies in all patients with heart disease as soon as they come under observation. Any subsequent relapsing ischaemic syndrome is then less likely to be misinterpreted. If the patient is seen for the first time on the occasion of the relapsing ischaemic syndrome, the error can hardly be avoided.

VIII

Outcome and Prognosis

Introduction

Peripheral embolism occurs almost exclusively in persons suffering from serious heart disease. The overall mortality of these patients is therefore greater than could be accounted for by the effects of limb embolism alone. Many patients who have survived embolism in a limb fall victim soon afterwards to a further embolism, peripheral, cerebral or visceral, others suffer a deterioration of the heart disease. The patient may die of some new disaster before it is possible to assess the fate of the embolised limb It was pointed out in Chapter VII that a deterioration of general condition may result in failure of a previously adequate collateral circulation and so precipitate gangrene in a limb which had previously made a good local recovery

In assessing the outcome of the cases of this study, we have been concerned principally with the local result in the limb, and as far as possible this has been classified independently of the general result. The following categories have been distinguished

1 Completely asymptomatic embolism ('silent embolism', 'embolie occulte')
2 Full recovery of the limb, without ischaemic after-effects ('anischaemic embolism', 'embolie manquée')
3 Recovery of the limb without necrosis but with persisting ischaemic after-effects, such as intermittent claudication or fibrotic contracture.
4 Minimal necrosis, dermal only, which heals, or appears capable of healing, without surgical intervention
5 'Primary gangrene'—necrosis of the whole thickness of at least one digit, occurring directly as a result of inadequacy of the local circulation of the limb, in a patient whose general condition is reasonably good.
6. 'Terminal gangrene'—necrosis of a digit or more, occurring only when the patient has become moribund from other causes, in a limb which has shown adequate collateral circulation for at least 7 days.
7 'Indeterminate'—the result in a patient who has died too soon after the onset of the ischaemic symptoms for the fate of the limb to be assessed.

Category (1) ('Silent embolism') is a group of limited application. There may be a small number among hospital patients, discovered by routine examination of the limb pulses and occasionally confirmed later by autopsy (*e.g.* Cases Nos. 42, 72, 75). Their number will depend upon the regularity with which routine examination of the limb pulses is made. As was shown in Chapter III, examination of patients with heart disease will reveal a number of arterial occlusions which appear to have caused no symptoms. In general, however, cases of 'silent embolism' do not come under observation.

Full examination of the limb arteries at autopsy will reveal some previously unsuspected old embolic occlusions which can be classified as examples of natural recovery, but it will not usually be known whether they caused any symptoms (*e.g.* Cases Nos. 31, 46, 69). Autopsy may also reveal some very recent embolic occlusions, possibly occurring shortly before death, which must be classified as 'indeterminate' (*e.g.* Cases Nos. 27, 64, 66).

Distinction between Category (2) ('full recovery') and Category (3) ('*recovery with persisting ischaemic after-effects*') is not always possible, for the patient has to be ambulant and under observation for at least some months before a final assessment can be made.

Classification of the cases of this study has therefore been simplified into four main groups:

I. *Survival of the limb*—comprising Categories (1), (2), (3) and (4) together. (Cases of aortic embolism have been included in this group only when both lower limbs have survived.)
II. *Primary gangrene*—Category (5)
III. *Terminal gangrene*—Category (6)
IV. *Indeterminate*—Category (7)

'Limb survival rate'

Two categories have been distinguished for limbs which become gangrenous, expressing the difference between gangrene truly attributable to a deficiency of local circulation ('primary gangrene') and that precipitated only by deterioration of the general circulation ('terminal gangrene'). In some cases there is room for difference of opinion in making this distinction. For comparison of the outcome in different groups of embolic incidents, reliance has therefore been placed mainly upon the 'limb survival rate', defined as the proportion of incidents in which the limb survives, expressed as a percentage of all incidents in the group. This figure is not influenced by subjective judgements as to the type of gangrene.

Comparison of results in different series

The above simplified scheme of four types of outcome and the limb survival rate can usually be applied to the results reported by other authors, and

with due regard to anatomical classification comparison of the outcome in different series can then be made.

Since the incidence of gangrene is mainly in embolism of the aortic bifurcation, iliac arteries and femoral arteries (see later in this chapter), it is of some

TABLE 29

Local result in 116 incidents of limb embolism

Site of embolism	Number of incidents	Number with survival of limb*	Number with primary gangrene	Number with terminal gangrene	Number indeterminate	Limb survival rate %
Upper limb						
Axillary	8	6	2†	—	—	75·0
Brachial	14	12	—	—	2	85·7
All upper limbs	22	18	2	—	2	81·8
Lower limb						
Aorta	17	4	8	3	2	23·5
C iliac	23	11	10	1	1	47·8
Ext iliac	2	2	—	—	—	—
C femoral; S femoral & D femoral	16; 3 (19)	14	3	2	—	73·7
S femoral	5	4	—	1	—	80·0
Popliteal	27	24	3‡	—	—	88·9
P tibial	1	1	—	—	—	—
All lower limbs	94	60	24	7	3	63·8
All sites	116	78	26	7	5	67·2
'Serious lower limb embolism'	66	35	21	6	3	53·0

interest to consider these as a separate group under the heading 'serious lower limb embolism'. This has been done in some of the tables

Outcome in embolic incidents of this study

There were 122 acute ischaemic incidents in the series, but 4 of them have been classified as pseudo-embolism and have therefore been excluded in the consideration of outcome. Two incidents of embolism of the deep femoral in patients who also had separate occlusion of the superficial femoral of the same limb have not been considered separately; the double occlusion has been grouped with the common femoral occlusions. The total number of embolic incidents analysed for outcome is therefore 116 and the results are shown in Table 29.

The most striking fact which emerges from Table 29 is that the limb survival rate varies inversely with the size of the occluded artery:

Site of embolism		*Limb survival rate*
Upper limbs—	Axillary:	75%
	Brachial	86%
Lower limbs—	Aortic	23%
	Common iliac	48%
	Common femoral	74%
	Popliteal.	89%

This principle is evident both in upper and lower limbs, though the number of upper limb embolisms is relatively small.

One other fact can be stressed: the very high limb survival rates in brachial and popliteal embolism. Not a single example of gangrene occurred in 14 incidents of brachial embolism (the limb survival rate in the group is not 100% because there were two indeterminate cases). There were three instances of gangrene in popliteal embolism, but in one of these there was also partial occlusion of the mouth of the common iliac in the same limb (by another embolus occluding the common iliac of the opposite side—Case No. 45) The other two examples both occurred in moribund patients, and although the period of observation did not allow of their formal classification as such, both were probably cases of terminal gangrene (Cases Nos 48, 74). It may be concluded that in brachial or popliteal embolism, unless the patient be moribund, the risk of gangrene is negligible.

Bilateral embolism—symmetry of local result

Table 30 shows symmetry of result in 24 cases of bilateral lower limb embolism. These comprised aortic embolism, embolism of both iliac arteries and embolism of both femoral arteries (indeterminate cases excluded). In the

majority of patients, the fate of the two limbs was similar. In the total of 24 cases there were only 5 in which there was survival of one limb and gangrene of

TABLE 30

Symmetry of result in bilateral lower limb embolism

(Indeterminate cases excluded)

Sites of embolism	Number of cases	Symmetrical result		Asymmetrical result
		Bilateral survival	Bilateral necrosis	Survival one side Necrosis one side
Aorta	15	4	8*	3†
Bilateral C iliac	4	1	2	1
L C iliac R Ext iliac	1	1	—	—
Bilateral C femoral	2	1	—	1
L C femoral R S femoral R D femoral	1	1	—	—
Bilateral S. femoral	1	1	—	—
All cases	24	9	10	5

* In 4 of these, gangrene was somewhat unequal in extent in the two limbs

† In one case, one limb had a prior common iliac occlusion, this was the limb which survived

the other. One case of aortic embolism had had occlusion of the left common iliac 16 months earlier, this limb survived while the other became gangrenous (Case No. 50, see discussion in Chapter X, Section (*d*)) There was one other example of aortic occlusion in a patient who had had a prior occlusion in one limb (R. common femoral, Case No 31) Though gangrene developed on both sides, it was much less extensive on the side with the prior occlusion. There were 13 cases of aortic embolism without prior occlusion, and only 2 of these had gangrene of one limb with survival of the other

Comparison with other authors' series

Analysis and comparison of the figures given by various authors on the outcome and results of treatment in embolism of the limbs are not always easy.

Differences in the character of the material and the basis of assessment may make it misleading to combine the findings of a number of different observers into a single large series. Many of the best known collected series contain a large proportion of cases treated by embolectomy and may therefore be unrepresentative of embolism in general. For example, the much-quoted series published by Danzis (1933) consisted of 129 cases of limb embolism collected from the literature in the U.S.A., Canada, Australia, Scandinavia, Germany and other European countries. It included 119 cases of embolectomy and only 10 cases not operated on.

TABLE 31

Assessment of outcome in peripheral arterial embolism

300 incidents, untreated or conservatively treated

After Haimovici (1950)

Site of embolism	Marked ischaemia and early death	Embolism followed by gangrene	Chronic post-embolic ischaemia	Anischaemic embolism	Undetermined degree of recovery	Silent embolism	Totals
Aorta	8	11	7	—	2	—	28
Common iliac	3	25	7	5	3	—	43
External iliac	1	7	1	1	—	—	10
Femoral	17	31	21	17	20	2	108
Popliteal	2	3	16	17	4	5	47
P. tibial	—	1	—	4	—	4	9
A. tibial	—	—	1	4	—	4	9
Axillary	4	1	1	6	1	—	13
Brachial	4	2	1	17	1	—	25
Radial	—	—	—	4	—	—	4
Ulnar	—	1	—	1	—	2	4
All sites	39	81	55	76	32	17	300
%	13·0	27·0	18·3	25·3	10·7	5·7	100·0

The most complete classification of outcome in a large series was made by Haimovici (1950), who analysed the results of 330 embolic incidents occurring in 228 patients during the years 1928 to 1947. 143 cases were taken from the records of the Mount Sinai Hospital, New York, and 85 from the private practice of Dr Irving Gilbert in the same city. Haimovici analysed these cases according to outcome and he distinguished 6 different types of result:

1. 'Embolism with marked ischemia and early death.'
2. 'Embolism followed by gangrene.'
3. 'Chronic post-embolic ischemia.'
4. 'Anischemic embolism.'
5. 'Embolism with undetermined degree of recovery.'
6. 'Silent embolism.'

The series studied by Haimovici included a total of 300 incidents conservatively treated or untreated and 29 incidents treated by embolectomy. Table 31, reproduced from his paper, shows his classification of the results in the 300 cases treated without operation.

TABLE 32

Limb survival rates in peripheral embolism

Comparison of results in present study and in study of Haimovici (1950)
'Serious lower limb embolism'

Material	Sites of embolism	Totals	Survival of limbs	Gangrene (primary or terminal)	Indeterminate	Limb survival rate %
Haimovici (1950) Cases treated without operation	Aortic	28	9	11	8	32·1
	Iliac	53	17	32	4	32·1
	Femoral	108	60	31	17	55·5
	All sites	189	86	74	29	45·5
Present study All Cases	Aortic	17	4	11	2	23·5
	Iliac	25	13	11	1	52·0
	Femoral	24	18	6	—	75·0
	All sites	66	35	28	3	53·0

For comparison with the writer's series, Haimovici's category (1) probably corresponds to Group IV ('Indeterminate') and his category (2) to Group II ('Primary gangrene') and Group III ('Terminal gangrene') taken together. Haimovici's category (5) seems to consist of surviving limbs, classified as having 'undetermined degree of recovery' because of lack of follow-up information on late ischaemic symptoms. Haimovici's categories (3), (4), (5) and (6) may therefore be combined to correspond with Group I ('Survival of the limb').

Table 32 shows a comparison of outcome in Haimovici's series and the writer's, based on these assumptions. The comparison has been restricted to 'serious lower limb embolism'. The limb survival rates for this group in the two series are substantially the same (Haimovici's series 45·5%, this series 53·0%) In both series, even in embolism of the larger arteries, there is a considerable proportion in which the limb survives without gangrene

So far the results in treated and untreated incidents have been considered together. In the next section the influence of treatment on outcome will be examined.

THE INFLUENCE OF TREATMENT ON LOCAL RESULT

1. CONSERVATIVE TREATMENT

109 embolic incidents had no arterial operation In 41 of these there was some form of medical treatment directed to the relief of ischaemia or the prevention of consecutive thrombosis, while in 68 there was either no treatment whatever or only palliative treatment, *e g* drugs for the relief of pain. The forms of treatment used were

ANTICOAGULANT DRUGS (30 incidents)	
Heparin alone (by intravenous injection):	21 incidents
Heparin plus oral anticoagulants:	7 incidents
Oral anticoagulants alone	2 incidents
VASODILATOR DRUGS (30+ incidents)	
Papaverine HCl (by intravenous injection)	16 incidents
Benzyl-imidazoline HCl ('Priscol') orally:	7 incidents
Pancreatic extract ('Padutin') intramuscularly·	7 incidents
Alcohol (as brandy) / Nicotinic acid orally	A few incidents
PROCAINE INFILTRATION OF LUMBAR GANGLIA	5 incidents
CENTRAL VASODILATOR METHODS (warming torso)	4 incidents

Comparison of treated and untreated embolism

Table 33 shows a comparison of the local results in untreated and treated embolic occlusions. The limb survival rate in untreated incidents was 74%, that in treated incidents was 56% (S.E. × 2 = 18·8). For 'serious lower limb

TABLE 33

Local result related to treatment

109 embolic incidents without arterial operation

Site of embolism	No treatment or only palliative treatment					Medical treatment for ischaemia				
	Total number	Outcome				Total number	Outcome			
		Survival of limb	Primary gangrene	Terminal gangrene	Indeterminate		Survival of limb	Primary gangrene	Terminal gangrene	Indeterminate
Upper limb										
Axillary	5	4	1*	—	—	3	2	1	—	—
Brachial	7	6	—	—	1	5	4	—	—	1
Lower limb										
Aorta	9	2	3	2	2	8	2	5	1	—
Common iliac	10	6	2	1	1	9	4	5	—	—
External iliac	2	2	—	—	—	—	—	—	—	—
Common femoral } S femoral + D femoral	12	8	2	2	—	6	4	1†	1	—
S femoral	4	3	—	1	—	1	1	—	—	—
Popliteal	18	18	—	—	—	9	6	3‡	—	—
P tibial	1	1	—	—	—	—	—	—	—	—
All sites	68	50	8	6	4	41	23	15	2	1
Limb survival rate	74%					56%				
'Serious lower limb embolism'	37	21	7	6	3	24	11	11	2	—
Limb survival rate	57%					46%				

* [illegible] days)

[illegible] erved 7 days).

F

embolism' the respective limb survival rates were 57% and 46% (S.E. × 2 = 26·0). It must be recognised that treated cases will tend to include a higher proportion of the graver ischaemic syndromes than untreated cases. This is so in the writer's material, for the treated group has a higher proportion of aortic and iliac occlusions (41%) than the untreated group (31%). In 'serious lower limb embolisms' the respective proportions of aortic and iliac occlusions were 71% and 57%. This probably accounts for the rather more unfavourable out-

TABLE 34

Embolic occlusions, all medically treated for ischaemia

Local result related to time of diagnosis

Site of embolism	Total treated	Diagnosed within 10 hours of onset		Diagnosed more than 10 hours after onset	
		Number of occlusions	Survival of limb	Number of occlusions	Survival of limb
Upper limb					
Axillary	3	1	1	2	1
Brachial	5	5	4	—	—
Lower limb					
Aorta	8	3	1	5	1
Common iliac	9	5	3	4	1
C femoral / S feml + D femoral	6	2	2	4	2
S femoral	1	—	—	1	1
Popliteal	9	3	1	6	5
All sites	41	19	12	22	11
Limb survival rate	56%	63%		50%	
'Serious lower limb embolism'	24	10	6	14	5
Limb survival rate	43%	60%		36%	

come in the treated cases, though the differences are not statistically significant. At all events, the figures certainly give no evidence of the efficacy of the methods of treatment used.

It is stressed by many authors that treatment of an embolic occlusion is of little avail if it is not begun soon after onset, and in assessing the value of treatment regard must be had to this factor. Table 34 includes treated cases only and compares the results in occlusions diagnosed within 10 hours of onset and those diagnosed after 10 hours. This table does show a higher limb survival rate in the occlusions diagnosed early, most pronounced in the group 'serious lower limb embolism'. However, the survival rate, even in the early diagnosed incidents of the latter group (60%) is not significantly higher than the corresponding rate in untreated incidents (57%) (S.E. × 2 = 26·1).

In the writer's material, therefore, no significant difference in limb survival rate can be shown *between treated and untreated embolic occlusions*.

2 OPERATIVE TREATMENT

Six embolic occlusions (in 5 patients) were treated by embolectomy. Arteriectomy was performed once. Only one of the 6 embolectomies can be called truly successful in the sense of restoring the lumen of the artery, and this operation was probably *unnecessary, for the embolus was at the brachial bifurcation* (Case No 66). In two other operations the limbs survived but the pulses were not permanently restored, and these operations therefore probably made no contribution to recovery Indeed, in one of them the temporary restoration of a free circulation in the main arterial trunk may have been partly responsible for the very severe muscle oedema, which resulted in fibrotic contracture (Case No. 7, already mentioned in Chapter VI and further discussed in Chapter XII).

Since the series of surgically treated cases is too small to provide any useful evidence of the value of embolectomy, the results of larger series published by other authors must be examined Table 35 shows the results given by 8 different authors during the period 1928 to 1954 In these eight series, amounting in all to a total of several hundred embolectomies,* there is only one series in which a limb survival rate of more than 50% is claimed for lower limb embolism. Warren, Linton and Scannell (1954) reported a series, collected from the records of the Massachusetts General Hospital during the period 1937–53, showing 49 surviving limbs out of 61 operations for embolism of the aorta, iliac and femoral arteries. This gives a limb survival rate of 80%, but the figure is not directly comparable with those given in this study, for these authors excluded indeterminate ('non-analyzable') cases from the total on which the limb survival rate was estimated Twenty-two cases were excluded from a total of 140 cases of

* The actual total of embolectomies recorded in these 8 papers is 1,037, but most of the series are collections from many different sources and some of the cases probably appeared *in more than one series*

aortic, iliac and femoral embolism. The number of surgically treated cases excluded as ' non-analyzable ' is not stated, but if we assume that the overall proportion of ' non-analyzable ' cases applies to this group then the total for the group must be increased from 61 to 72, and on this basis the limb survival rate becomes 68%. Even so, this is the most successful of the surgical series quoted, the next best being that of Key (1936) with a limb survival rate of 50% for all lower limb embolisms The limb survival rate for untreated aortic, iliac and femoral embolism in the writer's series is 57%, and that for all untreated lower limb embolisms 70%.

TABLE 35

Results of embolectomy according to eight published series

(Modified from Warren and Linton (1948)*)

Authors	Total cases	' Analyzable '	' Limbs saved '	Total lower limbs	' Lower limbs saved '
Petitpierre (1928)	129	126	44·4%	105	23 8%
Danzis (1933)	129	103	47·5%	—	28 8%
Pearse (1933)	282	282	30·0%	—	27 5%
Strombeck (1935)	327	120	50 0%	96	47·7%
Key (1936)	48	—	54·1%	44	50 0%
Lund (1937)	27	—	57 7%	—	47 4%
Reynolds and Jirka (1944)	16	13	87 5%	—	?
Warren, Linton and Scannell (1954)	?	78	84·0%	61†	80 0%

1954)

Interpretation of limb survival rates

It has already been shown that the limb survival rate in medically treated embolism is not better than that of untreated embolism. The published series of cases treated by embolectomy show that with one notable exception the limb survival rate in surgically treated embolism is also no better than that of untreated embolism. The series of embolectomies reported by Warren, Linton and Scannell is notable for the number of successful operations in aortic and iliac

embolism, but it is perhaps more an indication of what is possible than of what is usual. In general, the results of operative treatment, even in the hands of such experts as Key, are disappointing.

How are these findings to be interpreted? One difficulty is the general lack of clearly defined indications for treatment, which makes it impossible to be sure that the treated groups are truly comparable with each other or with the untreated groups. In the writer's material there were no sharply defined indications for treatment, the most important factor probably being duration of symptoms (*i e.* cases seen early were usually treated, while cases seen when the issue was already decided were usually left untreated) In many published series the indications are also ill-defined, depending on the personal predilections of the observer. Interest in the surgical problem (and perhaps some lack of experience of spontaneous recovery) seems to have influenced certain surgeons in favour of operation in many cases which might have done well without it With growing experience, some observers have changed their views, for example on the need for operation in upper limb embolism (*e g.* Warren and Linton (1948)). Even with a single observer, therefore, the indications for operation in a series gathered over a long period are not necessarily uniform.

One can conceive of a number of possible explanations for the apparent ineffectiveness of treatment

1 Treatment may never have any effect on the local result
2 Treatment may have a beneficial effect in some cases, but treated cases are in some way selected so as to include a higher proportion of serious occlusions than untreated cases.
3. Treatment may have a beneficial effect in some cases and a harmful effect in others.
4 In the great majority of cases, some other factor may be of much greater importance than treatment in determining the local result The influence of this factor therefore dominates the overall results, reducing to insignificance the small number of cases in which treatment exerts some effect.

Hypothesis (2) may have some bearing, but Hypothesis (4) probably explains the findings better than any other, and the ' dominant factor ' is almost certainly anatomical (Chapter IX). The natural endowment of arterial collaterals will determine whether spontaneous recovery is possible and if this factor is favourable, then treatment would not improve the chances of recovery. A series of surgically treated cases will contain the following groups:

(*a*) Cases which would do well without operation.
(*b*) Cases which could do well only as a result of operation.

Group (*b*) will include· (i) Operative successes,
(ii) Operative failures.

The overall results in an operated series will depend upon the relative numbers in Groups (*a*) and (*b*), and if (*a*) are very much more numerous than (*b*), then, allowing for operative failures, the results of a large series will not be significantly better than those of an untreated series, *especially if there is a high proportion of the less serious forms of embolism, i.e. brachial, femoral and popliteal.*

If operative treatment is of value only in a small proportion of cases, then it becomes important to define the indications for operation and to establish the clinical data which enable these indications to be recognised with the minimum of delay. This problem is referred to later in this chapter (' Problems of clinical prognosis ') and also in Chapter XII.

TABLE 36

Survival period of patient in 122 embolic incidents

Embolic site	Total	Survival period of patient after embolism								
		0–24 hrs	1–3 dys	4–10 dys	11–30 dys	1–12 mths.	1–2 yrs	2–5 yrs	5+ yrs	?*
Upper limbs										
Axillary	10	1	—	1	—	3	—	—	—	5
Brachial	14	1	1	—	1	6	1	1	1	2
Lower limbs										
Aorta	17	2	1	6	3	2	1	1	1	—
Iliac	28	1	—	1	2	8	2	1	10	3
Femoral	25	—	—	—	6	9	5	1	1	3
Popliteal†	28	—	1	3	1	15	—	1	2	5
All sites	122	5	3	11	13	43	9	5	15	18

* All in this column lived at least 30 days in good health, but were subsequently lost sight of

† Includes one posterior tibial

Apart from possible effects of treatment, there are considerable differences in the overall figures of local results in series of cases reported by different observers. These figures are probably influenced by selection of cases, particularly by the relative numbers of occlusions at different anatomical sites. Where the observer's special interest leads to more systematic examination in search of arterial occlusion, more of the less serious forms of embolism are recognised and the overall survival rate then becomes higher. This is well exemplified by

the figures of old spontaneously recovered embolic occlusions in patients with mitral stenosis, recorded in Chapter III. If these occlusions be added to the clinical series of untreated embolisms, the combined series shows an overall limb survival rate of 85%.

Mortality

All studies of peripheral embolism show a high general mortality, due mainly to associated conditions such as cerebral or visceral embolism and heart failure. Strombeck (1935) investigated the results of 327 cases of embolectomy, performed in 60 different Swedish hospitals during the years 1912 to 1932. He found that 207 (63%) died in hospital. Of the 120 who were discharged (61 with good circulation in the limb, 59 with amputations), half had died within 3 years of operation Two-thirds had died within 5 years, and only one-eighth were alive 10 years after discharge from hospital. (Actually, not all of these patients could have been followed for more than three years.)

TABLE 37

Main cause of death in 55 patients

1 *Death directly due to limb embolism*	
'Shock', due to aortic embolism	1 patient
Gangrene, due to limb embolism;	11 patients
2 *Death due to associated disease*	
Heart disease	
Heart failure	18 patients
Bacterial endocarditis	6 patients
Embolic obturation of mitral valve	1 patient
Internal embolism	
Cerebral	8 patients
Mesenteric	2 patients
Cerebral and mesenteric	1 patient
Subarachnoid haemorrhage	1 patient
Dicoumarol poisoning	1 patient
3. *Death due to coincident disease*	
Broncho-pneumonia	1 patient
Acute enteritis·	1 patient
Acute miliary tuberculosis	1 patient
Carcinoma of the bronchus;	1 patient
Carcinoma of the stomach	1 patient
Total·	55 patients

Survival periods in the writer's series are shown in Table 36. In 91 of the 122 embolic incidents the patient survived at least 30 days, but only in 29 (24%) was the survival period known to be more than one year. There were a further 18 incidents after which the patient survived at least one month in good health but was then lost sight of. If we assume that one-third of these lived a year, the total proportion with one year's survival would still be no more than 29%. In 15 embolic incidents the patient is known to have survived for more than 5 years. The causes of death in 55 patients are shown in Table 37.

Reappearance of suppressed pulses after embolism

Reappearance of one or more of the suppressed arterial pulses distal to an embolic occlusion was observed in a total of 33 incidents, of which 17 were subsequently anatomically verified. The figures are shown in Table 38. When more than one pulse in a limb returned, it was usual for the more proximal pulse to appear first and the more distal ones considerably later. For example,

TABLE 38

Reappearance of suppressed pulses after embolic occlusion

(4 incidents of 'pseudo-embolism' and 3 incidents of migrating embolus excluded)

Site of embolism	Number of incidents	Number with return of pulses	Interval to return of pulses		
			0–7 days	8–28 days	More than 28 days
Upper limbs					
Axillary	8	5	2	1	2
Brachial	14	10	4* †	2	4
Lower limbs					
Aorta	17	4	2‡	1	1
Iliac	26	4	—	1	3
Femoral	23	3	—	1	2
Popliteal	27	7	2	5	—
All sites	115	33	10	11	12

* One after embolectomy.
† One pulse returned while the artery was being palpated
‡ One return only transient (for 7 days)

in one case of common iliac occlusion the femoral pulse reappeared in 2 months, the dorsal pedal in 3 months and the popliteal some months later (Case No. 50). In a case of axillary occlusion the brachial pulse appeared in 4 days and the radial in 7 days (Case No. 70). Early reappearance of pulses (*i.e.* within 4 weeks) was common in axillary, brachial and popliteal occlusions: it was noted in 16 of 49 embolisms affecting these arteries, but only in 5 of 66 embolisms in the aorta, iliac arteries and femoral arteries.

In 30 of the 33 occlusions in which pulses reappeared, the limb survived without necrosis, but in the remaining 3 massive gangrene occurred. In Case

TABLE 39

Late results in surviving limbs

36 embolic occlusions with adequate follow-up

Site of embolism	Observation periods	Total cases	Full recovery of limb	Chronic ischaemic symptoms
Axillary	<3 months	1	1	—
	3–6 months	4	2	2
	All periods	5	3	2
Brachial	<3 months	1	1	—
	3–6 months	2	2	—
	>6 months	1	—	1
	All periods	4	3	1
Aorta	6 months	2	—	2
Common iliac	3–6 months	2	1	1
	>6 months	6	2	4
	All periods	8	3	5
External iliac	6 months	1	1	—
Common femoral	3–6 months	1	—	1
	>6 months	4	1	3
	All periods	5	1	4
Popliteal	<3 months	5	4	1
	3–6 months	3	2	1
	>6 months	3	2	1
	All periods	11	8	3
All sites	All periods	36	19	17

No. 21 an occlusion of the right common iliac was followed by gangrene of the leg and foot and the limb was amputated. A weak pulse was felt in the femoral artery of the stump 4 years later. In case No. 50 there was occlusion of the left common iliac with good recovery: a femoral pulse reappeared at the groin 2 months later, followed within a year by the dorsal pedal and popliteal pulses. Sixteen months after the left iliac embolism there was an embolism of the aortic bifurcation and all pulses in the two limbs were again suppressed. The left limb again survived, but the right became gangrenous and was amputated. A weak femoral pulse reappeared on the left side one year later and on the right side after a further 18 months.

In Case No 81 the course of events was enigmatic Following an embolism of the aortic bifurcation, one limb lost all its pulses but recovered rapidly; the other had a transient return of its femoral pulse after 3 days, with improvement of the ischaemic signs, but again lost its pulses and then became gangrenous In Case No 69, after embolism of the axillary artery the brachial pulse returned within 10 days and the radial within 23 days; though there was no gangrene a severe ischaemic contracture developed in the hand. (This case also had a long-standing prior occlusion in the brachial artery of the same limb.)

Reappearance of suppressed pulses after embolism is therefore fairly common, especially in upper limbs. In some cases of proved embolism it may occur within a very few days. In general, this phenomenon is associated with adequate collateral circulation, but there is a small number of cases in which despite return of pulsation in the arterial trunk the collateral circulation proves inadequate for survival of the distal part of the limb.

Late results in surviving limbs

There were 36 embolic occlusions in which the observation period permitted some assessment of the degree of final recovery. The results of these follow-up observations are summarised in Table 39. In upper limb embolism 6 of 9 cases had full recovery, in lower limb embolism 13 of 27 cases. The residual symptoms complained of can be classified as follows:

Ischaemic fibrosis (severe)·	2 occlusions
Intermittent claudication.	8 occlusions
Pain in foot in cold weather.	2 occlusions
Cold feeling in limb in cold weather·	2* occlusions
Rest pain in foot	1 occlusion
Small chronic ulcer of foot.	1 occlusion
Slight wasting of forearm flexors:	1 occlusion
Limb ' tires easily '·	1 occlusion
Limb ' feels heavy ':	1 occlusion

* These two patients also had intermittent claudication and are included in that group of 8 patients

These late results were mostly in patients admitted to hospital with acute ischaemic symptoms. In cases of old spontaneously recovered embolism, found by routine examination of the limb pulses, the proportion of patients with chronic ischaemic symptoms is far lower (Chapter III).

PROGNOSIS

Accuracy of prognosis in this study

The standard of accuracy of prognosis (of local result) in the embolic incidents of this study is indicated in Table 40 There were major errors of prognosis in 13 occlusions out of a total of 52 in which prognosis was attempted within 3 days of onset of ischaemic symptoms. Details of the 13 errors are condensed in Table 41

TABLE 40

Accuracy of prognosis in limb embolism

52 embolic occlusions in which prognosis was attempted within 3 days of onset

Time after onset	Number with prognosis attempted	Prognosis correct or nearly correct	Prognosis wrong
0–10 hours	25	21	4
10–24 hours	14	10	4
1–3 days	13	8	5
0–3 days	52	39	13

With one notable exception, the standard of accuracy of prognosis was satisfactory The exception is in embolism of the aortic bifurcation, which accounts for 7 of the 13 errors As there were only 12 aortic occlusions with determinate result which were seen within 3 days of onset, the incidence of major errors of prognosis in this group is inordinately high. Only one of these errors was an ' error of pessimism ' This patient was seen only 20 minutes after onset and he then had signs of grave ischaemia, but subsequently there was rapid improvement and both limbs survived (Case No. 4) One error was of little consequence, since gangrene developed only when the patient was dying of heart failure (Case No 80). One error was due to wrong diagnosis of the site of the embolism and to erroneous assessment of the ischaemic signs (Case No. 50 —see Chapter VII). The 4 remaining errors are of special interest and they are dealt with in the next section.

Deceptive course in aortic embolism

There are some cases of embolism in which, after initial steady improvement in the ischaemic signs, there is a sudden regression with rapid deterioration and

TABLE 41

13 major errors of prognosis in limb embolism

Case No	Site of embolism	Duration of symptoms	Type of error	Reason for error
4	Aorta	20 mins	'Error of pessimism'	Prognosis made too early (only 20 mins after onset)
6	Aorta*	13 hrs	'Error of optimism'	Sudden regression after initial improvement
20	R common femoral	11½ hrs	Optimism	? Effect of unsuitable treatment (elevation)
21	R common iliac	3 days	Optimism	Unusual course, with very gradual regression
22	Aorta*	30 hrs.	Optimism	Late regression after initial improvement
45	L popliteal	5½ hrs	Optimism	Unrecognised partial occlusion of L common iliac
47	Aorta*	28 hrs	Optimism	Late regression after initial improvement
50	Aorta	2½ hrs	Optimism	Wrongly diagnosed as R common iliac (Previous recovery from L C iliac embolism)
54	L axillary	16 hrs.	Optimism	Wrong assumption of probable recovery in upper limb occlusion
74	L popliteal	24 hrs	Optimism	Deterioration of general condition precipitated terminal gangrene
76	L common iliac	? 3 hrs	Optimism	Wrong assessment of ischaemic signs Unrecognised earlier occlusion of L external iliac
80	Aorta	48 hrs	Optimism	General deterioration due to cardiac failure
81	Aorta*	48 hrs	Optimism	Sudden regression after initial improvement

* These 4 cases are discussed in the following section.

necrosis of the limb This was seen only in embolism of the aortic bifurcation and there were 4 examples (Cases Nos. 6, 22, 47, 81). These 4 cases have been marked with an asterisk in Table 41.

It might be supposed that a regression of this kind is due to consecutive thrombosis, but only in one of the 4 examples quoted was extensive consecutive thrombosis found at autopsy (Case No. 6). The cause is obscure, but it may perhaps be related more to the ' dynamics ' of the general circulation than to any local developments in the limb. The collateral circulation of an artery so large as the aorta is probably much more sensitive to changes in the general arterial blood-pressure than that of smaller arteries.

Whatever its explanation may be, this tendency in aortic embolism makes prediction of the result impossible, and for this reason conservative treatment is not practicable in any case seen early enough for operative treatment (Chapter XII).

Problems of clinical prognosis

In embolism of the brachial or popliteal arteries the local result is almost invariably good and gangrene need never be anticipated except in a moribund patient. There is therefore rarely any clinical problem of prognosis in these cases.

Aortic occlusions in which the collateral circulation initially appears adequate not uncommonly undergo sudden regression, with rapidly ensuing gangrene, and there is no means of recognising the cases which will deteriorate in this way. There is therefore no clinical problem of prognosis in aortic embolism, every case seen early enough should be subjected to embolectomy, which offers the best hope of averting gangrene The chief clinical problem is one of diagnosis, this has already been discussed in Chapter VII

It is in iliac embolism, and to a lesser extent in femoral and axillary embolism, that clinical prognosis presents the greatest problem A considerable proportion of these cases will recover spontaneously, but there are some who will not, and for these embolectomy should be performed with the least possible delay. How are these latter cases to be recognised? Some authors (*e g.* Richards (1954)) have recommended a trial of medical measures with a period of observation up to three hours, operation to be performed if there has been no improvement within this time The writer's experience indicates that if signs of very severe ischaemia have persisted for more than two hours after onset the outlook for the limb is very poor In a case with severe ischaemic signs, rapid improvement was never observed after the lapse of two hours from onset, either following treatment or without it, though it was seen several times in cases observed within an hour of onset (Cases Nos 4, 20, 75) After two hours, further improvement is almost invariably a gradual process, probably depending upon *growth* of collaterals. It should usually be possible to form an opinion on the local prognosis

in any case of embolism of the iliac, femoral or axillary artery seen more than two hours after onset. The signs most useful in assessing the severity of the ischaemia are:

1. *'Waxen pallor' or extreme pallor with cyanotic mottling.* There were 11 embolic occlusions in which one of these signs was present at first examination. In 8 of them primary gangrene ensued, one was indeterminate (Chapter VI).
2. *Pallor persisting in the whole foot or hand for more than 2 hours after onset.* This sign was present in 6 of 8 embolic occlusions in which primary gangrene ensued, but in none of 9 in which the limb survived (Chapter VI).
3. *Extensive sensory impairment in the skin.* In cases of aortic and common iliac embolism examined within 24 hours of onset there were 6 in which primary gangrene ensued All these had sensory impairment to the knee or higher In 9 limbs which survived, only one had sensory loss to the knee (this was at $1\frac{3}{4}$ hours) and two to mid-tibia (at 20 minutes). One had sensory loss to mid-tarsus only and 5 had no demonstrable sensory loss at all (Chapter VI, Table 22). In cases seen more than 2 hours after onset, therefore, sensory impairment of the whole foot or more was closely correlated with gangrene.
4. *The 'venous refilling sign'.* There were 14 embolised limbs in which venous refilling was classified as 'negligible' or 'sluggish'; only two of these survived. Six limbs in which the venous refilling was classified as 'fairly good' or 'normal' all survived (Chapter VI).

The evidence already discussed in Chapter VI indicates that in limbs which have adequate collateral circulation these signs of grave ischaemia should begin to regress within two hours of onset. If still present in a case seen after two hours they indicate inadequacy of the collateral circulation.

Case No 54 is worthy of attention in the light of these principles. The patient was seen 16 hours after onset of symptoms from an occlusion of the axillary artery and her general condition was good. Though there was no pallor, the ischaemic signs were unusually severe for an upper limb embolism and sensory loss extended nearly to the elbow. Prognosis was guided too rigidly by the principle that gangrene is unlikely in upper limb embolism, and it proved to be wrong. The anatomical study (Chapter IX) shows that good collaterals are usual in the upper limb, but that there are occasional exceptions even here (Fig. 21). Provided two hours have elapsed since onset, the objective ischaemic signs represent the most reliable guide to prognosis.

In the majority of cases, the application of these principles should enable an immediate decision to be made as to whether operative treatment is indicated.

IX

Anatomical Variations in Arterial Collaterals

Introduction

It has been stressed by some writers (*e g.* Massé (1925)) that collateral circulation is a vital process in the living organism and that it cannot be studied in the cadaver This is true, but the basis of collateral circulation is essentially anatomical. Unless we have a clear idea of the nature, size and numbers of the available collateral pathways, we cannot usefully discuss local physiological factors such as vasomotor reactions which may influence their function. How numerous and how large are the collateral arteries which must carry the circulation into a limb when the main arterial trunk is suddenly occluded? Do the macroscopic arterial anastomoses form the most important pathways, or is the limb more dependent upon communications between the minute ' pre-capillary ' ramifications? Does the natural degree of anatomical development of arterial anastomoses vary greatly in different persons? If some individuals have a much richer collateral system than others, then this fact may have some part in accounting for varying degrees of ischaemia in different cases of limb embolism

Embolism is the ' purest ' form of acute arterial occlusion, for it occurs suddenly. The arterial segment initially occluded is usually limited in length and it often occurs in persons whose arteries are healthy. In such cases, collateral circulation depends upon the natural ' anatomical ' anastomoses, not augmented by any prior process of abnormal development

There is a great wealth of information on arterial anatomy in the standard anatomical works of the past two hundred years, and most of these describe and illustrate collateral arterial anastomoses of the larger calibre, demonstrable by dissection. However, these works do not answer the question most germane to the clinical problem of limb embolism, *i e.* whether there are individuals with gross deficiency of the collateral system in general or in particular anatomical regions and, if so, how common such individuals may be. Even in works such as those of Quain (1844) and Adachi (1928), which deal in great detail with variations in arterial ramification, the incidence of variations is described for each artery separately and they do not provide the answer to this question

in any case of embolism of the iliac, femoral or axillary artery seen more than two hours after onset. The signs most useful in assessing the severity of the ischaemia are.

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2. *Pallor persisting in the whole foot or hand for more than 2 hours after onset* This sign was present in 6 of 8 embolic occlusions in which primary gangrene ensued, but in none of 9 in which the limb survived (Chapter VI).
3. *Extensive sensory impairment in the skin* In cases of aortic and common iliac embolism examined within 24 hours of onset there were 6 in which primary gangrene ensued All these had sensory impairment to the knee or higher. In 9 limbs which survived, only one had sensory loss to the knee (this was at 1¾ hours) and two to mid-tibia (at 20 minutes). One had sensory loss to mid-tarsus only and 5 had no demonstrable sensory loss at all (Chapter VI, Table 22) In cases seen more than 2 hours after onset, therefore, sensory impairment of the whole foot or more was closely correlated with gangrene
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In the majority of cases, the application of these principles should enable an immediate decision to be made as to whether operative treatment is indicated.

strating fine anastomoses than the white lead suspension. Olovson apparently injected only one internal iliac artery in each subject, and he therefore provided no evidence on symmetry of arterial collaterals.

Olovson's study has given valuable systematic information on the ilio-femoral anastomoses and their variations in different persons. It showed that there are some individuals with gross deficiency of the larger anastomoses. However, conclusions drawn from the investigation of one particular collateral field are not necessarily applicable to another. The study described in this chapter was directed to the fields of collateral blood supply related to some of the common clinical types of limb embolism It was designed to obtain some information on variations in the arterial collateral systems of different individuals, to compare the collateral systems of lower limbs with those of upper limbs and to examine whether the extent of development of arterial collaterals in a particular individual is usually symmetrical

MATERIAL AND METHODS OF STUDY

Procedure

The procedure consisted of ligation of the main arteries of the limbs at the points of bifurcation where embolism commonly occurs, followed by injection of radio-opaque fluid and radiography The method of arterial ligation was designed to imitate the effects of impaction of an embolus, which usually fills the lowest segment of the main trunk and occludes both its divisions. Both divisions were therefore ligated at their origins and a ligature was placed on the main trunk a few centimetres proximal to the bifurcation. This process of ' exclusion ' of the lowest segment of the main trunk was completed by ligation of every branch arising from the main trunk between the occluding ligatures.

Position of occluding ligatures

The arteries studied were the upper brachial and the lower brachial in the upper limb and the common femoral and popliteal in the lower limb The ligation method in each case was as follows (Fig. 11).

UPPER BRACHIAL

1 A ligature on the brachial trunk at its origin
2 A ligature on the brachial trunk immediately below the origin of the deep brachial.
3 A ligature on the deep brachial at its origin.
4 Ligation of all branches of the brachial trunk arising between the main occluding ligatures

LOWER BRACHIAL.

1 A ligature on the brachial trunk, approximately 5 cm above its terminal bifurcation.

Olovson (1941) made an admirable survey of the anatomical writings on arterial anastomoses and quoted in summary the contributions of more than thirty of the best-known authorities to this subject, from Winslow (1732) to Rauber-Kopsch (1939). He concluded that '. . . precise information on the frequency, extent and calibre of the anastomotic pathways is almost completely lacking'.

In 1922, Leriche expressed the view that the macroscopic, dissectable, arterial anastomoses were largely an anatomists' myth and that they have little part in the maintenance of collateral circulation, which he held to depend upon minute anastomoses between the 'pre-capillary' arterial ramifications, especially those of the muscles. This view was based mainly upon the work of his colleague Rassat (1922), who attempted to demonstrate arterial anastomoses by dissection in a series of 18 human foetuses and almost completely failed to do so.

Subsequent anatomical studies in the adult, both by dissection and by radiographic methods (*e g* Massé *(1925)*, Olovson *(1941)*), *have* vindicated the teachings of the anatomists on the reality of the larger arterial collaterals. Ivanov (1928), in experiments on artificial embolism in dogs, showed that if paraffin were injected into the femoral artery in amounts sufficient to fill the main trunks down to the ankle, then gangrene invariably resulted. He concluded that no system of 'pre-capillary' anastomoses could carry an adequate collateral circulation if the larger arteries were put out of action in this way These experiments were performed upon living limbs, and there was close correlation between the incidence of gangrene and the anatomical extent of the arterial occlusions.

The existence of macroscopic arterial anastomoses and their essential part in the maintenance of collateral circulation have thus been established. Quiring (1949) has given a systematic account of the anatomical basis of collateral circulation in the different regions of the human body, together with a survey of some of the experimental investigations on collateral circulation in animals.

There is still relatively little information on the general incidence of anatomical variations in arterial collaterals in different human subjects. Olovson (1941) made a valuable study of the anastomoses between the internal iliac artery and the femoral artery in human cadavers, using a method of injection of radio-opaque fluid into the internal iliac, followed by stereoscopic radiography. He injected a total of 107 adults and 31 foetuses, using two different fluids In a series of 38 adults, injected with a white lead-gum arabic suspension, there were three subjects in which no anastomoses could be demonstrated and two which showed only a single anastomosis In the remaining 33 subjects the number of anastomoses shown ranged from two to five. In a series of 69 adults, injected with 'Teichmann's fluid' (chalk and mercuric sulphide, suspended in a mixture of linseed oil and carbon disulphide), there were 33 subjects in which no anastomoses could be demonstrated However, Olovson considered that this fluid, which requires warming to render it mobile, was less reliable for demon-

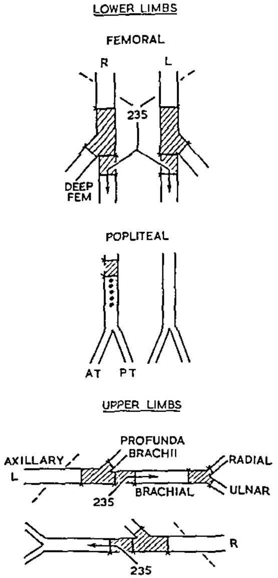


FIG. 11 *Injection diagrams*

In *Figs. 12 to 22*, the technique of ligation and injection used in each experiment is indicated in a diagram of the type illustrated here. Hatching of an arterial segment indicates complete exclusion of that segment by ligation of all branches arising between the main occluding ligatures. Popliteal arteries have been occluded by insertion of a plasticine plug through an incision in the popliteal fossa, lead shot being included to make the position of the plug visible in the arteriogram. Popliteal occlusion is therefore represented by stippling.

2. A ligature on the radial at its origin
3. A ligature on the ulnar at its origin
4. Ligation of all branches of the brachial trunk arising between the main occluding ligatures.

COMMON FEMORAL:

1. A ligature on the common femoral trunk at its origin.
2. A ligature on the deep femoral at its origin.
3. A ligature on the superficial femoral immediately below the origin of the deep femoral
4. Ligation of all branches of the common femoral trunk arising between the main occluding ligatures

POPLITEAL:

The bifurcation of the popliteal is very deeply placed and attempts to expose it may cause injury to collaterals. The popliteal was therefore occluded by a plasticine plug, inserted into the artery at the level of the knee-joint, where it is easily accessible, and pushed down towards the bifurcation (The aim was to reach this but, as some of the illustrations show, this was not always achieved) Small lead shot, embedded in the plasticine, make it visible in the arteriogram

Position of injection cannula

In the lower limb the cannula was tied into the superficial femoral immediately below the occluding ligature and was directed distally The collateral system of the femoral was therefore demonstrated by retrograde flow from the femoral to the iliac system, that of the popliteal by downward flow towards the foot.

In the upper limb the cannula was tied into the brachial trunk immediately below the origin of the deep brachial and was directed distally The collateral system of the upper brachial was therefore demonstrated by retrograde flow from the brachial to the axillary system, that of the lower brachial by downward flow towards the hand

In each experiment, either both lower limbs or both upper limbs were injected The upper arteries (common femoral or upper brachial) were always occluded on both sides The lower arteries (popliteal or lower brachial) were sometimes occluded on both sides, sometimes on one side only and sometimes left intact (Fig. 11).

Injection fluid

The fluid used for injection must possess certain qualities if good arteriograms of the finer vessels are to be secured Apart from its expense, a homogeneous fluid such as iodised oil is not suitable, for if the injection pressure be raised above a certain level (in one experiment made, approximately 200 mm

sure of less than 150 mm is usually inadequate. In principle it would seem advisable to use as high a pressure as possible, but in practice a pressure of 325 mm not infrequently causes rupture of small vessels and consequent extravasation of the contrast fluid. The majority of the injections were carried out at a pressure of 235 mm, but a certain number were done at 325 mm. A comparison of the results in these two series shows no significant difference between them (p. 121).

Irrigation of the arterial system before injection

There has been controversy as to the advisability of irrigating the arterial system with saline or citrate solution before injection, in order to remove any blood or post-mortem clots which may lie in the arteries. Some workers have advised it (*e g* Petrén (1929), Kurkowsky (1934)), while others have thought it harmful rather than helpful (*e g* Reinberg (1922), Hill (1929)). Olovson's practice was to wash out the arterial field studied ' in both directions ' with physiological saline, and as he found that this brought away numbers of clots he considered irrigation advisable.

The problem is not simple. If it is possible entirely to free the arterial field under study from post-mortem clots by irrigation, then this is obviously desirable. *The ideal method would be to irrigate with citrate solution immediately* after death, before any post-mortem clotting could occur, but this is rarely practicable. After post-mortem clots have formed the situation is difficult, for irrigation must be carried out in such a way as to impel any clots from the smaller to the larger arteries. Otherwise clots may be moved from large arteries, which they do not completely obstruct, to become firmly impacted into smaller arteries. When clots are present, therefore, the only safe method of irrigation would be from the venous side through the capillary system into the arteries. This is technically very difficult, for post-mortem clots are usually much more numerous and much larger in the veins than in the arteries.

In fact, examination of arteries in the cadaver shows that though post-mortem clots are often present in arteries they tend to be mainly in the larger arteries and *are not* usually so large as fully *to occlude them*. *A thin, oily* injection fluid seems to run past these clots very easily. Irrigation, even if it brings away *a number of clots, gives no guarantee that all clots have been re*moved or, more importantly, that none of them have been driven into and impacted *in smaller arteries*. For these reasons, irrigation was not employed in this study.

Duration of injection

The injection was continued for 20 to 30 minutes. The inflow was stopped before X-ray photographs were taken.

Hg.) this fluid will pass over into the venous system, completely confusing the arteriogram. A suspension of radio-opaque powder must be used, fine enough to enter the smallest arteries, yet too coarse to pass over into the veins. Various suspensions, mostly of lead or barium compounds, some aqueous and some oily, have been used by different workers for *post-mortem arteriography*. In aqueous suspensions gum acacia is usually employed as the suspending agent. The contrast powder must be fine and free from large particles or agglomerations and it must have a high molecular weight so that it is sufficiently radio-opaque. The suspension must be free-running, even when cooled in the vessels of the cadaver. Sedimentation must not be too rapid and there must be no tendency to caking in the suspension.

Trials were made with various aqueous suspensions of barium compounds, but it was soon found that 'Hauch's fluid' (Hauch (1913)) is superior to these and it was therefore used throughout the rest of the study. Hauch's fluid has the following composition.

Red oxide of lead (Pb_3O_4)	8 parts by weight
Paraffin oil:	8 parts
Oil of turpentine	5 parts

The mixture is carefully triturated in a mortar and then filtered through a thick wad of gauze The fluid flows freely into the finer arterial branches and casts a very dense shadow in the arteriogram. When stirred up, the powder will remain in suspension long enough to ensure good injections, especially if the fluid in the reservoir be kept agitated during the injection. The oily medium effectively prevents caking of the powder, even when there is some sedimentation. When the rate of inflow is slow, care should be taken to arrange the injection tubing so that there are no dependent parts below the cannula into which sedimentation can occur, otherwise the inflow may consist mainly of the oily vehicle and the contrast in the arteriogram will be inadequate. If the cannula be the lowest part of the system, then sedimentation will not prevent good injections being made

Technique of injection

The injection was made by gravity, using a reservoir with a mechanical agitator to minimise sedimentation The reservoir was suspended by a cord passing over a pulley placed at a height of 4 metres above floor level, which enabled injection pressures of up to 400 mm of mercury to be attained. The system was calibrated by means of a mercury manometer.

Injection pressure

Experiments with different injection pressures showed that the most suitable range is between 200 and 300 mm of mercury (Figs. 12, 13, 14). A pres-



Fig. 13 (same experiment as Fig. 12). Films taken after a further 10 minutes' flow at 150 mm Hg.



Fig. 14 (same experiment as Fig. 12). Films taken after a further 15 minutes' flow at 235 mm Hg



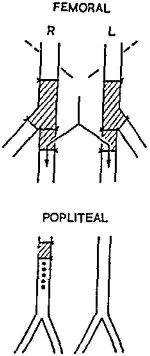


FIG 12

Experimental post-mortem arteriography Effect of varying injection pressure Bilateral injection into superficial femoral arteries with ligation of the femorals and ligation and plugging of the right popliteal as shown in the injection diagram Films taken after 10 minutes' flow at 100 mm Hg (Compare with Figs 13 and 14)

FIG. 12

CASE 45 (H.T) 77 F
INJECTED 8 11 48
(40 HRS P-MORTEM)
PRESSURE 235 mm Hg
DURATION OF FLOW 30 min

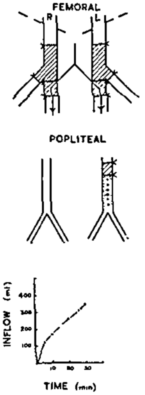




FIG 15

Experimental post-mortem arteriography No 45 Lower limbs Occlusion of both common femoral arteries and lower part of left popliteal

Grade of collateral circulation

R common femoral II (' good ')
L common femoral II (' good ')
L popliteal I (' very good ')

Radiography

If the aim is to identify particular arteries, then stereoscopic radiography is essential. In this study, however, the aim was to compare the general extent of collateral circulation at different sites and in different subjects, and ordinary radiography is adequate for this. Stereoscopic films were taken in some experiments, but were not done as a routine.

Material investigated

A total of 66 cadavers were injected, but for purposes of comparison those injected with barium suspensions were excluded The series therefore comprises 57 adult cadavers, all injected with Hauch's fluid. Thirty subjects were male and 27 female, with ages ranging from 40 years to 90 years, 40 subjects being over 70 years old. The subjects were hospital patients dying of various diseases but not known before death to have either ' emboligenic ' heart disease or occlusive vascular disease. A certain number were shown by the injection to have occlusive vascular disease, not recognised during life. In most cases this was not of a degree or situation likely to impair interpretation of the arteriogram, but there was one case (Experiment 39) in which the demonstration of collateral circulation may have been affected (see later in this chapter—' Effect of arteriosclerosis ') The injections were made at periods after death varying from 4 hours to 44 hours, but the great majority were done within 24 hours.

Interpretation of results

The extent of collateral circulation was estimated mainly by the degree of filling of the main arterial trunks beyond the occlusion and by the general richness of visualisation of smaller connecting arteries. Some further estimate was obtained by recording the rate of inflow of the injection fluid throughout the injection. This has been charted in most of the experiments (see injection diagrams accompanying Figs 15 to 22). The characteristic inflow chart shows an initial phase of rapid inflow lasting 5 to 10 minutes, this represents filling of the vascular system of the limb distal to the occlusion and is more pronounced in lower limbs than in upper limbs. The rate of inflow then falls off rather sharply and the subsequent gradient of the curve indicates the rate of continuing flow through collaterals leading back to the torso. This gradient usually accords very well with the grade of collateral circulation as estimated from the arteriogram (see injection diagrams accompanying Figs. 15 to 22).

An arbitrary scheme of classification was applied to the extent of collateral circulation demonstrated by this technique Six grades were distinguished, and these are exemplified for the common femoral artery:

CASE 57 (J F) 70 M

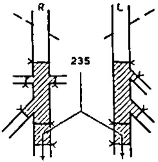
INJECTED 9·4·49

(27 HRS P-MORTEM)

PRESSURE 235 mm Hg

DURATION OF FLOW 30 min

FEMORAL



POPLITEAL ARTERIES INTACT

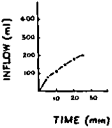


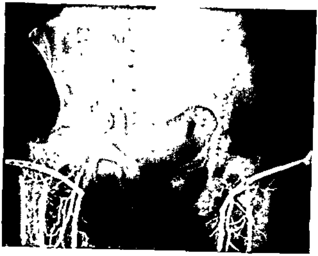


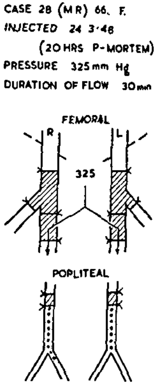
Fig 17

Experimental post-mortem arteriography No 57 Lower limbs Occlusion of both common femoral arteries

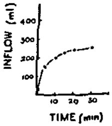
Grade of collateral circulation·

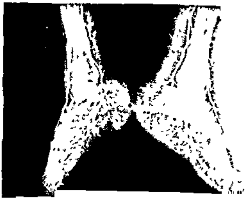
R common femoral VI ('nil')
L common femoral VI ('nil')











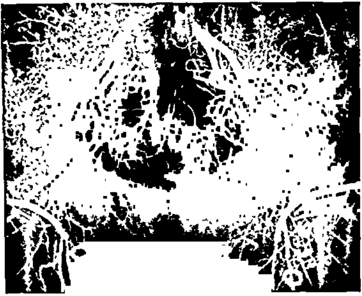
L

Fig 16

Experimental post-mortem arteriography No 28 Lower limbs Occlusion of both common femoral and both popliteal arteries

Grade of collateral circulation

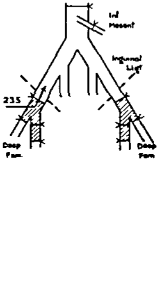
R common femoral, V ('minimal')
L common femoral, IV ('poor')
R popliteal I ('very good')
L popliteal I ('very good')



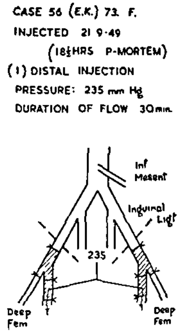
CASE 56 (E K) 73 F
INJECTED 29 I 49
(20 HRS P-MORTEM)
(II) PROXIMAL INJECTION
PRESSURE 235 mm Hg
DURATION OF FLOW 10 min

FIG. 19

Experimental post mortem arteriography No 56 After completion of the injection distal to the common femoral occlusions, a second injection has been made into the right external iliac artery proximal to the occlusion, as shown in the injection diagram (The abdominal aorta and the inferior mesenteric artery have been ligated in order to exclude the injection from the mesenteric arteries) The film taken after this second injection shows that the pelvic vessels, which failed to fill by collateral flow from the distal injection, are in fact patent, both the large trunks and their finer ramifications (Compare with Fig 18)







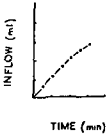
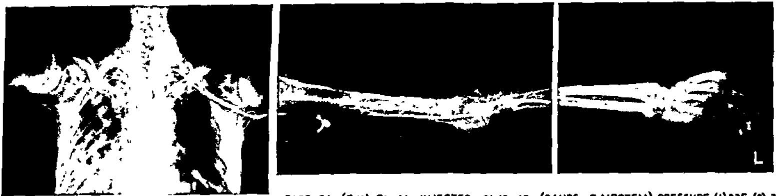


FIG 18

Experimental post-mortem arteriography No 56 Lower limbs Occlusion of both common femoral arteries

Grade of collateral circulation

R common femoral V ('minimal')
L common femoral IV ('poor')



CASE 54 (E.H) 71 M INJECTED 31·12·48 (24 HRS P-MORTEM) PRESSURE (1) 235 (2) 325
DURATION OF FLOW (1) 15 min
(2) 15 min

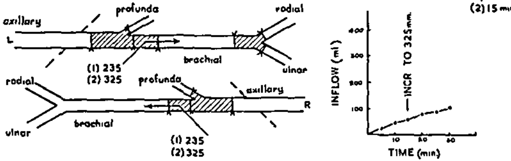


FIG 21

FIG 21 Experimental post-mortem arteriography No. 54 Upper limbs Occlusion of both upper brachial and left lower brachial arteries

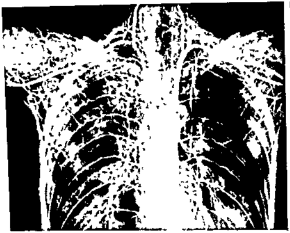
Grade of collateral circulation

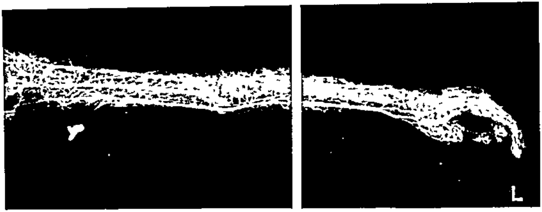
R upper brachial V ('minimal')
L upper brachial III ('fair')
L lower brachial V ('minimal')



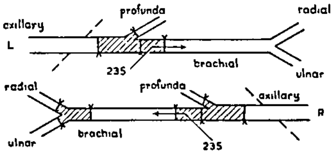


Note In this experiment, the rate of flow indicated poor collateral circulation. After 15 minutes' flow at 235 mm, the injection pressure was raised to 325 mm and the injection was then continued for a further 15 minutes





CASE 49 (HH) 67 M INJECTED 20·11 48 (7 HRS P-MORTEM)



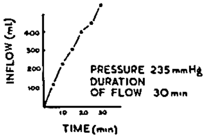
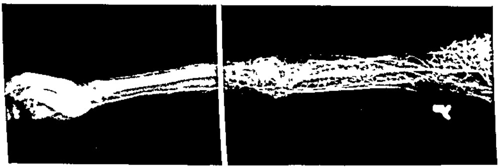
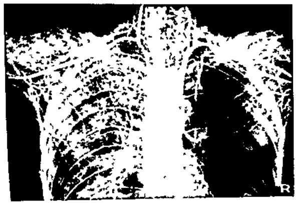


FIG 20

FIG 20 Experimental post-mortem arteriography No 49 Upper limbs Occlusion of both upper brachial arteries and right lower brachial





Grade of collateral circulation R upper brachial · I ('very good')
L upper brachial I ('very good')
R lower brachial · III ('fair')

ficiencies in the system of arterial collaterals, either absence or very small size.

There are some possible theoretical objections to this interpretation. Firstly, the injection fluid might not easily enter the finer arterial collaterals, so that many of them might not be visualised. Olovson found that 'Teichmann's fluid' has some disadvantages in this respect. The method used in this study, however, does provide some check on this possible error, for it can be seen to what extent the finer arteries have been injected in the distal part of the limb. If the injection here has run freely into the small arterial divisions it may be presumed that it would demonstrate collateral channels of at least equivalent size. In any case, an error of this type would affect all cases equally and should still allow comparison between them as to the presence of injectable collaterals.

Secondly, collateral arteries may fail to fill because they are occluded by *post-mortem* clots. Some experiments were done to test this possibility. In a number of experiments in which the injection had shown inadequate collateral circulation, a second injection was made into the same arterial trunk on the other side of the occlusion. In the case of the femoral, the second injection was made into the iliac system, proximal to the 'excluded' segment. In the case of the lower brachial, the second injection was made into the radial artery, distal to the excluded segment. Examples of this type of two-stage arteriography are illustrated in Figs. 18 and 19 and Figs. 21 and 22. In Fig. 18, the first injection is seen to have injected the limb very fully, but the collateral circulation, demonstrated by retrograde flow into the pelvic system is inadequate (right side 'Grade V', left side 'Grade IV'). The second injection, made into the right external iliac, proximal to the excluded segment of the common femoral, shows a very complete injection of the pelvic system with extensive filling of the finer arterial ramifications (Fig. 19). If the failure in the first injection to demonstrate collateral communications between the femoral and iliac systems were due to obstruction by clots, it must be presumed that these clots were universally present in, and confined to, communications between the finer ramifications of the two systems. This appears highly unlikely and the possibility may fairly be rejected.

There are two other pieces of evidence in favour of the adequacy of the technique. Firstly, collateral circulation, as demonstrated by the method, exhibits striking symmetry (p. 120). It could hardly be supposed that technical errors would apply bilaterally in nearly every subject. Secondly, the method rarely fails to demonstrate good collaterals in the upper limb, and there seems no reason why technical errors should apply only to lower limbs.

Results of injection experiments

The results of the series of 57 experiments are set out in Schedules 1, 2, 3 and 4 and summarised in Tables 42, 43, 44 and 45.

GRADE I ('Very good'):	Complete filling of the iliac arteries and extensive *filling of their finer ramifications.*
GRADE II ('Good'):	Complete, or almost complete, filling of the iliac arteries.
GRADE III ('Fair'):	*Partial, but substantial, filling of the iliac arteries.*
GRADE IV ('Poor').	Fragmentary filling of the iliac arteries.
GRADE V ('Minimal'):	No visible filling of the iliac arteries. A few small arteries visible proximal to the inguinal ligament
GRADE VI ('Nil')·	No arteries visualised proximal to the inguinal ligament

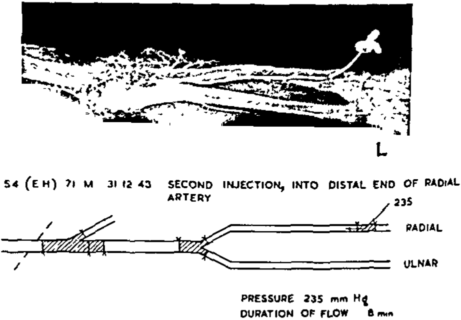


FIG 22 Experimental post-mortem arteriography No 54 After completion of the proximal injection into the left brachial artery, a further injection was made into the left radial artery This demonstrates that the radial and ulnar arteries, which failed to fill by collateral flow from the injection proximal to the lower brachial occlusion, are in fact patent (Compare with Fig 21)

Examples of some of these grades are illustrated in Figs. 15 to 18. Similar systems of grading were applied to the other three arterial fields studied, and examples are illustrated in Figs. 15 to 21.

Adequacy of the technique

Failure to demonstrate collateral circulation by means of this technique of post-mortem arteriography has been interpreted as indicating anatomical de-

SCHEDULE 2

Popliteal artery—Results of 24 experiments (42 arteries)

Number of experiment	*Age of subject*	*Sex of subject*	*Grade of collateral circulation*	
			Left	*Right*
6	70	M	II	II
9	40	M	II	II
12	70	F	III	IV
13	70	M	I	I
14	90	M	I	I
15	70	F	I	IV*
16	71	M	IV	IV
17	83	F	III	V*
18	78	M	IV	III
28	66	F	I	I
29	84	F	III	III
30	81	F	II	IV*
31	59	F	II	II
32	59	M	II	I
33	84	F	I	I
34	78	M	IV	V
35	71	F	III	III
36	90	F	III	II
37	68	M	III	—
38	58	M	III	—
39	72	F	IV	—
41	75	M	I	—
45	77	F	I	—
66	74	F	—	I

* Instances of asymmetrical collateral circulation

SCHEDULE 1

Common femoral artery—Results of 40 experiments

Number of experiment	Age of subject	Sex of subject	Grade of collateral circulation Left	Right
6	70	M	II	II
9	40	M	I	I
10	46	F	I	I
12	70	F	I	II
13	70	M	I	I
14	90	M	II	II
15	70	F	II	II
16	72	M	I	II
17	83	F	V	V
18	78	M	IV	V
19	76	F	V	VI
20	66	M	VI	V
21	69	M	II	II
22	87	M	III	—*
23	80	M	V	V
24	68	M	V	V
25	58	M	V	IV
26	77	M	III	III
27	73	M	VI	VI
28	66	F	V	V
29	84	F	V	VI
30	81	F	V	V
31	59	F	V	VI
32	59	M	I	I
33	84	F	II	II
34	78	M	II	II
35	71	F	V	VI
36	90	F	II	II
37	68	M	I	I
38	58	M	III	III
39	72	F	II	II
41	75	M	I	I
45	77	F	II	II
55	80	F	IV	II†
56	73	F	IV	V
57	70	M	VI	VI
58	90	M	V	V
59	89	M	I	I
63	80	M	V	VI
66	74	F	V	IV

* R-sided injection failed through faulty cannulisation.

† The only instance of asymmetrical collateral circulation observed in femoral arteries

TABLE 42

Common femoral artery—grade of collateral circulation

Summary of results of 40 experiments (79 arteries)

Grade of collateral circulation shown	Number of arteries	Percentage of all arteries
I ('Very good')	16	
II ('Good')	21	
III ('Fair')	5	
'Adequate'*	42	53%
IV ('Poor')	5	
V ('Minimal')	22	
VI ('Nil')	10	
'Inadequate'*	37	47%
'Very inadequate'*	32	40%

* For definition of these terms see p 119

TABLE 43

Popliteal artery—grade of collateral circulation

Summary of results of 24 experiments (42 arteries)

Grade of collateral circulation shown	Number of arteries	Percentage of all arteries
I ('Very good')	13	
II ('Good')	9	
III ('Fair')	10	
'Adequate'	32	76%
IV ('Poor')	8	
V ('Minimal')	2	
VI ('Nil')	—	
'Inadequate'	10	24%
'Very inadequate'	2	5%

SCHEDULE 3

Upper brachial artery—Results of 17 experiments (34 arteries)

Number of experiment	Age of subject	Sex of subject	Grade of collateral circulation Left	Right
42	66	F	I	I
43	74	F	I	I
44	73	F	II	II
46	78	F	III	III
47	65	M	I	I
48	70	F	II	II
49	67	M	I	I
50	86	F	II	II
51	64	M	II	II
52	71	M	II	II
53	47	M	II	I
54	71	M	III	V*
60	74	F	III	III
61	83	F	II	II
62	53	M	II	II
64	58	F	I	I
65	89	F	I	I

* The only instance of asymmetrical collateral circulation observed in upper brachial arteries

SCHEDULE 4

Lower brachial artery—results of 17 experiments (21 arteries)

Number of experiment	Age of subject	Sex of subject	Grade of collateral circulation Left	Right
42	66	F	—	I
43	74	F	—	II
44	73	F	—	I
46	78	F	—	III
47	65	M	I	—
48	70	F	II	—
49	67	M	—	III
50	86	F	I	—
51	64	M	II	—
52	71	M	—	II
53	47	M	I	—
54	71	M	V	—
60	74	F	III	III
61	83	F	I	I
62	53	M	—	I
64	58	F	I	I
65	89	F	I	I

Comparison of collateral circulation in different groups

In recording the results of the experiments, six grades of collateral circulation were distinguished, but when comparing the findings in different subjects it would not be right to lay great stress upon finer degrees of difference. The results have therefore been collected into three main groups.

Adequate collaterals:	Grades I, II and III
Inadequate collaterals:	Grades IV, V and VI
Very inadequate collaterals:	Grades V and VI

In Tables 42, 43, 44 and 45 the findings at each of the four anatomical regions studied are classified according to this system.

Comparison between upper and lower limbs

Comparing common femoral and upper brachial arteries:

COMMON FEMORAL 79 arteries (average age of subjects 72·6)

COLLATERAL CIRCULATION:	*Inadequate*	37 arteries (47%)
	Very inadequate	32 arteries (40%)

UPPER BRACHIAL 34 arteries (average age of subjects 69)

COLLATERAL CIRCULATION:	*Inadequate*	1 artery	(3%)
	Very inadequate	1 artery	(3%)

For *Very inadequate* groups:

Difference: 37
S E. × 2 = 12·5

Age and sex

Close comparison of collateral circulation at different ages is not justifiable, for the material does not include enough of the younger subjects, for the common femoral

SUBJECTS OVER 80 YEARS		21 arteries
	Adequate	10 arteries
	Inadequate	11 arteries
SUBJECTS UNDER 60 YEARS		12 arteries
	Adequate	8 arteries
	Inadequate	4 arteries

This point may be of some clinical importance, but further study is needed for its elucidation.

There was no significant difference in arterial collaterals in the two sexes.

TABLE 44

Upper brachial artery—grade of collateral circulation

Summary of results of 17 experiments (34 arteries)

Grade of collateral circulation shown	Number of arteries	Percentage of all arteries
I ('Very good')	13	
II ('Good')	15	
III ('Fair')	5	
'Adequate'	33	97%
IV ('Poor')	—	
V ('Minimal')	1	
VI ('Nil')	—	
'Inadequate'	1	3%
'Very inadequate'	1	3%

TABLE 45

Lower brachial artery—grade of collateral circulation

Summary of results of 17 experiments (21 arteries)

Grade of collateral circulation shown	Number of arteries	Percentage of all arteries
I ('Very good')	12	
II ('Good')	4	
III ('Fair')	4	
'Adequate'	20	95%
IV ('Poor')	—	
V ('Minimal')	1	
VI ('Nil')	—	
'Inadequate'	1	5%
'Very Inadequate'	1	5%

Comparison of collateral circulation in different groups

In recording the results of the experiments, six grades of collateral circulation were distinguished, but when comparing the findings in different subjects it would not be right to lay great stress upon finer degrees of difference. The results have therefore been collected into three main groups:

Adequate collaterals:	Grades I, II and III
Inadequate collaterals:	Grades IV, V and VI
Very inadequate collaterals:	Grades V and VI

In Tables 42, 43, 44 and 45 the findings at each of the four anatomical regions studied are classified according to this system.

Comparison between upper and lower limbs

Comparing common femoral and upper brachial arteries:

COMMON FEMORAL 79 arteries (average age of subjects 72·6)

COLLATERAL CIRCULATION.	*Inadequate*	37 arteries (47%)
	Very inadequate	32 arteries (40%)

UPPER BRACHIAL 34 arteries (average age of subjects 69)

COLLATERAL CIRCULATION.	*Inadequate*	1 artery	(3%)
	Very inadequate	1 artery	(3%)

For *Very inadequate* groups

Difference 37
S E. × 2 = 12·5

Age and sex

Close comparison of collateral circulation at different ages is not justifiable, for the material does not include enough of the younger subjects, for the common femoral

SUBJECTS OVER 80 YEARS		21 arteries
	Adequate	10 arteries
	Inadequate	11 arteries
SUBJECTS UNDER 60 YEARS		12 arteries
	Adequate	8 arteries
	Inadequate	4 arteries

This point may be of some clinical importance, but further study is needed for its elucidation.

There was no significant difference in arterial collaterals in the two sexes.

TABLE 44

Upper brachial artery—grade of collateral circulation

Summary of results of 17 experiments (34 arteries)

Grade of collateral circulation shown	Number of arteries	Percentage of all arteries
I (' Very good ')	13	
II (' Good ')	15	
III (' Fair ')	5	
' Adequate '	33	97%
IV (' Poor ')	—	
V (' Minimal ')	1	
VI (' Nil ')	—	
' Inadequate '	1	3%
' Very inadequate '	1	3%

TABLE 45

Lower brachial artery—grade of collateral circulation

Summary of results of 17 experiments (21 arteries)

Grade of collateral circulation shown	Number of arteries	Percentage of all arteries
I (' Very good ')	12	
II (' Good ')	4	
III (' Fair ')	4	
' Adequate '	20	95%
IV (' Poor ')	—	
V (' Minimal ')	1	
VI (' Nil ')	—	
' Inadequate '	1	5%
' Very Inadequate '	1	5%

Comparison of collateral circulation in different groups

In recording the results of the experiments, six grades of collateral circulation were distinguished, but when comparing the findings in different subjects it would not be right to lay great stress upon finer degrees of difference. The results have therefore been collected into three main groups:

Adequate collaterals:	Grades I, II and III
Inadequate collaterals.	Grades IV, V and VI
Very inadequate collaterals·	Grades V and VI

In Tables 42, 43, 44 and 45 the findings at each of the four anatomical regions studied are classified according to this system.

Comparison between upper and lower limbs

Comparing common femoral and upper brachial arteries:

COMMON FEMORAL 79 arteries (average age of subjects 72·6)

COLLATERAL CIRCULATION·	*Inadequate*·	37 arteries (47%)
	Very inadequate	32 arteries (40%)

UPPER BRACHIAL 34 arteries (average age of subjects 69)

COLLATERAL CIRCULATION:	*Inadequate*	1 artery	(3%)
	Very inadequate.	1 artery	(3%)

For *Very inadequate* groups.

Difference. 37
S E. × 2 = 12·5

Age and sex

Close comparison of collateral circulation at different ages is not justifiable, for the material does not include enough of the younger subjects; for the common femoral

SUBJECTS OVER 80 YEARS		21 arteries
	Adequate	10 arteries
	Inadequate	11 arteries
SUBJECTS UNDER 60 YEARS		12 arteries
	Adequate	8 arteries
	Inadequate	4 arteries

This point may be of some clinical importance, but further study is needed for its elucidation

There was no significant difference in arterial collaterals in the two sexes.

Effect of arteriosclerosis

In a number of subjects the arteriograms showed evidence of arteriosclerotic intimal changes. These appear as irregularity or narrowing of the outlines of the arterial trunks and occasionally segmental occlusion In an attempt to determine whether this type of chronic arterial disease has any influence on the grades of collateral circulation demonstrated, the arteriograms have been classified according to the degree of intimal change shown in the femoro-popliteal trunk. Four degrees were distinguished:

1. *Nil* No recognisable intimal irregularity.
2. *Slight* Irregularities without appreciable narrowing.
3. *Moderate* Considerable narrowing of the arterial trunk.
4. *Severe* Segmental occlusion at one or more points.

In the total of 40 experiments on lower limbs the findings were as follows:

Degree of intimal arteriosclerotic change	*Number of subjects*	
Nil	3	24
Slight	21	
Moderate	9	16
Severe	7	

Of the 7 subjects which showed segmental occlusion, 6 had it in the lowest part of the superficial femoral artery or the popliteal, 5 of them on one side only and 1 on both sides There was only one subject in which the occluded segment reached the upper part of the superficial femoral (R), and this is the experiment in which it is possible that the collateral system of the common femoral may have been affected (Experiment 39, female subject aged 72 years *Collateral circulation of common femoral, L Grade II, R: Grade II).*

To assess the possible effect of intimal arteriosclerosis on the results of the experiments, 24 subjects in the first two categories ('Nil' and 'Slight' intimal change) are compared with 16 subjects in the last two categories ('Moderate' and 'Severe' *intimal change). The results of this comparison are shown in* Table 46, and this shows no significant difference in the results of the two groups.

(It is possible nevertheless that chronic obliterative arterial disease may influence collateral circulation in the living limb when there is an embolic *occlusion* The present study gives no information on this point)

Symmetry of arterial collaterals

The grade of collateral circulation demonstrated showed striking symmetry in the great majority of the experiments In the case of the common femoral artery, 39 subjects with bilateral injection included only a single example in which collateral circulation was 'adequate' on one side and 'inadequate' on

TABLE 46

Arteriosclerotic intimal disease

Effect on collateral circulation
Common femoral artery

Degree of arteriosclerotic changes	Number of subjects	Number of arteries	Collateral circulation (arteries)
'Slight' or 'Nil'	24	47	'Adequate' 23
			'Inadequate' 24 (51%)
'Moderate' or 'Severe'	16	32	'Adequate' 19
			'Inadequate' 13 (40%)

(S E × 2 = 22 6)

the other (Experiment 55, see Schedule 1). Applying the six standard grades, the two sides fell into the same grade in 26 subjects and into adjacent grades in 12 subjects (Schedule 1).

Influence of injection pressure

Some of the injections were made at a pressure of 235 mm mercury and some at 325 mm (p. 100) A comparison can be made between the results obtained with the common femoral artery in the two series:

42 common femoral injections at 235 mm Hg.

COLLATERALS *adequate*	23 arteries	(55%)
COLLATERALS *inadequate*	24 arteries	(45%)

37 common femoral injections at 325 mm Hg

COLLATERALS *adequate*	19 arteries	(51%)
COLLATERALS *inadequate*	18 arteries	(49%)

There is no significant difference between these two groups of experiments.

CONCLUSIONS

The anatomical study showed considerable variation in the degree of anatomical development of arterial collaterals in different persons, especially in lower limbs.

In the collateral field of the common femoral artery, deficiency of anastomoses was found in a considerable proportion of subjects. In the collateral fields of the brachial and popliteal arteries deficiencies were rare

The anatomical development of arterial collaterals is symmetrical in most subjects.

X

Arterial Spasm in Embolism of the Limbs

Introduction

In certain conditions, a state of continuous spasmodic contraction may appear in a limb artery, lasting for a long period and sometimes resulting in gangrene of the limb. The best example of this is traumatic arteriospasm, which is occasionally seen when an artery has been contused by a fractured bone or when a missile has passed close to the vessel (Kuttner (1920), Montgomery and Ireland (1935), Griffiths (1940), Cohen (1941)). In such cases an intense continuous spasmodic contraction of the vessel may be directly observed at operation. It usually extends for a considerable distance along the artery, proximally as well as distally from the point of injury and it sometimes involves many branches of the main trunk, causing the most profound ischaemia. Kinmonth (1952) showed that it is a locally induced muscular spasm, not dependent upon any spinal reflex mechanism, and that the most effective treatment is local application of a solution of papaverine to the contracted vessel Intravenous injection of the drug is without effect.

Arterial spasm, usually less intense in degree, is occasionally seen in association with thrombo-phlebitis of the adjacent deep veins. It may produce acute ischaemic signs, but is rarely so severe as to cause gangrene (Pallin (1929), *Trémolières and Veran (1929), Lawen (1934), Uggeri and Massone (1938)*). Case No 57 was an example of this condition, which is thought to be caused by irritation of the adventitial nervous plexus of the artery by an inflammatory process in the adjacent vein.

During the past thirty years, many authors have put forward the theory that a condition of arterial spasm may be set up by impaction of an embolus and that this spasm aggravates the ischaemia by constricting collateral channels. This theory has been widely accepted, as the following quotations show:

> . . In this case also, a continuous state of spasm is set up in the vessel wall Not only is this shown by the clinical signs but it has often been directly observed during the operation of embolectomy. *Peiser* (1932)

It has long been known that the artery in the neighbourhood of an embolus is spasmodically contracted . . . The vascular tube round the embolus may be narrowed by persistent spasm for a distance of up to 8–10 cm *Denk* (1934)

What are the relative effects of these factors in deciding the result of an embolic accident? Is the pure hydraulic effect of the occlusion more important than the vasomotor effect? The anatomical and clinical data now allow us to say that the latter is the more important. *Haimovici* (1937)

It must be remembered, however, that the deficient circulation is only partly due to the plug in the major artery and that a *concomitant massive vasoconstriction*, involving the obstructed artery distal to the plug and the available collateral pathways, greatly aggravates the impairment of the circulation and may give a false impression of the height of the obstruction *De Takats* (1942)

As a matter of fact, cases of acute embolic occlusion are not infrequently seen which open and develop an effective collateral circulation without any therapeutic assistance. Many more would respond in a similar manner were it not for the fact that when an embolus suddenly occludes a peripheral artery, the arterial bed in that extremity and sometimes in the opposite extremity as well is thrown into a greater or lesser degree of spasm I have seen instances in which a minute embolus lodged in the periphery of a leg has given rise to bilateral vasospasm of such magnitude that an organic occlusion of the bifurcation of the abdominal aorta was simulated

Atlas (1942)

The artery immediately peripheral to the occlusion is always in spasm by the time direct observation of the vessel is possible Sometimes small peripheral emboli initiate immediate vaso-spastic phenomena which disappear spontaneously

Reynolds and Jirka (1944)

. the circulatory insufficiency, the reduction of blood-flow distally, that is to say the vasoconstriction in the network of collaterals The more spasm there is in the collateral network the more stasis will result and the more easily thrombosis will occur. *Leriche* (1947)

. . the vasoconstrictor reflexes set up by an embolism are more injurious than the effects of its occlusion of the main arterial trunk *Leriche* (1947)

When the embolus lodges, spasm occurs in all cases and affects not only the vessel involved, but the collateral circulation This spasm is Nature's protective mechanism to aid in emptying the blood vessel distal to the embolus so that the vessel will not be thrombosed This keeps the vessel available for the circulation to be reestablished to it through the accessory vessels *Pratt* (1949)

In embolic occlusion, when arteriospasm occurs proximal to the site of the occlusion and involves smaller collateral arteries, it may be of such magnitude that it completely overshadows the organic occlusion itself Such spasm may seriously interfere with determining the site of the obstructing embolus. *Holden* (1952)

In cases of arterial embolism in which the pain has begun abruptly, we have always been dissatisfied with the explanation that the occlusion of the artery by a clot is the cause The probability that arterial spasm is responsible for the pain in embolism, either directly or as a result of the ischemia it produces, is so logical and fits so well with recorded observations regarding suddenness of onset, severity and the difficulty of localising the pain that we believe there is a direct cause and effect relationship.

Allen, Barker and Hines (1955)

All cases of sudden arterial occlusion have one common factor, namely, interruption of the continuity of the arterial lumen This is not, however, the major cause of ischemia for only minimal ischemia may be produced when a peripheral artery is compressed or ligated In many instances, particularly when pain is sudden or severe, it appears that arterial spasm is present. *Allen, Barker and Hines* (1955)

The theory that an embolus which obstructs the main artery of a limb also excites a state of active vasoconstriction in the collateral vessels upon which survival of the limb depends implies an 'anti-adaptive' reaction, which would aggravate the effects of the embolic occlusion. Anti-adaptive reactions are not unknown in human pathology, though most of them are exaggerations or perversions of reactions which are in their essential nature adaptive or protective. Certain attempts have been made to represent arterial spasm as having some protective function. Pratt, in the passage quoted above, thought that spasm might help to prevent consecutive thrombosis in the arterial trunk distal to the embolus and so '. keep it available for the circulation to be re-established to it'. Reynolds and Jirka (1944) thought that ' . such a spasm may be considered beneficial when, for instance, an embolus lodges at the femoral bifurcation and is thereby prevented from migrating to the popliteal region' This assumes that migration from the femoral to the popliteal would increase the threat to the limb, but the experience of this study does not support such an assumption (Chapter VIII) Peiser (1932) held the contrary view that arterial spasm is *harmful* because it might prevent distal migration of the embolus

In any case, hypotheses such as those of Pratt or Reynolds and Jirka could apply only to spasm of the main arterial trunk. Spasm of collateral vessels could have no other effect than to aggravate the ischaemia and could fairly be called an anti-adaptive reaction. It would not be proper to reject the theory of embolic arteriospasm on purely teleological grounds, yet a certain scepticism is not out of place, and valid evidence of arteriospasm must be required before the theory could be accepted.

Pickering (1951), in a critical examination of current conceptions of arterial spasm, concluded that '. . . the idea is entertained too freely and uncritically in current thought and writing'. He pointed out that in many instances phenomena attributed to arterial spasm were susceptible of other explanations, and in the case of arterial embolism he drew attention to the possibility of

embolic migration (Chapter VII) Richards (1954) considered that some of the clinical phenomena he had observed in connection with limb embolism must be due to arterial spasm, either reflex or myogenic, but he thought that '. . in most cases the so-called arterial spasm has a simpler explanation ' Jepson (1955) thought that severe and persistent arterial spasm following the impaction of an embolus ' . . must be uncommon, and the decrease in arterial diameter distal to the occlusion is probably more often due to lowering of arterial pressure '.

The evidence upon which the theory of embolic arteriospasm has been based will therefore be critically examined, with the guiding principle that arterial spasm should not be accepted as an explanation of clinical or experimental observations if any other explanation is equally possible

EVIDENCE FOR ARTERIAL SPASM IN EMBOLISM

The evidence which has been put forward in support of the theory of embolic arteriospasm can be classified under the following headings

1. Clinical observations

(*a*) Established states of arterial spasm
(*b*) Comparison with the effects of arterial ligation.
(*c*) Observations at operations on arteries
(*d*) Clinical evolution of symptoms and signs in embolism
(*e*) Extent of the ischaemic signs in limb embolism
(*f*) Embolic migration
(*g*) Character and site of pain in limb embolism
(*h*) Effect of sympathetic ganglion block and vasodilator drugs.
(*i*) ' Pseudo-embolism '
(*j*) Pulse deficiencies proximal to site of embolic impaction.

2. Experimental observations

(*k*) Experimental embolism
(*l*) Ligation experiments on animal arteries
(*m*) Distension experiments on animal arteries

The evidence under each of these headings will be considered in turn.

1 CLINICAL OBSERVATIONS

(a) Established states of arterial spasm

Arterial spasm can occur from trauma and also in association with thrombophlebitis This is not evidence that it can occur in embolism, but it does show that arterial spasm is possible In traumatic spasm the contraction of the vessel extends for a long distance, proximally from the point of injury as well as distally.

(b) Comparison with the effects of arterial ligation

Many authors have stated that the ischaemic effects of arterial ligation are less severe than those of embolic occlusion. Key (1936) thought that the incidence of gangrene after embolism was much greater than after ligation. (He did not attribute this to arterial spasm but to consecutive thrombosis.) Allen, Barker and Hines, in the passage already quoted, considered that in embolism, arterial spasm must often be an important factor in the causation of ischaemia '. . . for only minimal ischemia may be produced when a peripheral artery is compressed or ligated '.

This reasoning cannot be accepted without closer examination. In the first place, ligation of a normal artery in a normal human limb must be a very rare procedure. Ligation has been performed for injuries to arteries, especially war wounds, and in these cases there is often injury to collaterals as well as the main trunk This factor *would operate to the disadvantage of ligation* in a comparison with embolism. (It probably explains, in part, the high incidence of gangrene after ligation of the popliteal artery. See below.) On the other hand ligation has also been performed for chronic arterial disease such as aneurysm and in cases of this type there may have been extensive prior development of collaterals, so that ligation of the main trunk carries little risk.

Certain anatomical considerations must also be borne in mind For example, ligation of the common femoral may leave intact the common femoral bifurcation, which will provide a return pathway to the main trunk through the collateral system of the deep femoral Embolism of the femoral will usually occlude the mouth of the deep femoral and so block this return pathway

Enough has been said to indicate the need for caution in comparing the effects of ligation and embolism, but there is a more weighty argument. The primary assumption that arterial ligation carries a smaller risk than embolism must itself be doubted It is certainly not the case with the *popliteal artery*. Popliteal embolism rarely results in gangrene and its ischaemic effects are often trivial (Chapter VIII). Ligation of the popliteal carries a high risk of gangrene (see below) In the case of other arterial trunks also there is good reason to contest the assertion that surgical ligation is a relatively harmless procedure Figures of the incidence of gangrene following ligation of limb arteries have been given by Wolff (1908), Makins (1919) and Heidrich (1921), and these figures are summarised in Table 47. Further figures, based on surgical experience in World War II are given by De Bakey and Simeone (1946), and these are summarised in Table 48.

The figures given by these various authors show some differences, but they give no basis for the assumption that the ischaemic effects of arterial ligation are commonly slight. The local results of embolism at various sites, according to the experience of this study, are summarised in Table 49.

TABLE 47

Incidence of gangrene after arterial ligation

(After Wolff (1908), Heidrich (1921) and Makins (1919))

Site of arterial ligation	Proportion of cases developing gangrene		
	Wolff	Heidrich	Makins
Subclavian	4 8%	9 7%	—
Axillary	15 0	9·8	—
Brachial	4·0	3 1	—
Upper limbs	7 8	5·9	—
Aorta	—	100·0	—
Common iliac	50 0	100 0	—
External iliac	11·2	13·4	16 6%
Common femoral	25·0	21 8	25·9
Superficial femoral	12 7	10 4	14 1
Popliteal	14 9	37·2	32 5
Lower limbs	20 4	20 0	—

TABLE 48

Ligation of arteries for war injuries

Incidence of gangrene

(After De Bakey and Simeone (1946))

Artery ligated	Number of cases	Loss of limb	
		Number	%
Common iliac	13	7	53 8
Femoral	517	275	53·2
Popliteal	502	364	72 6
Axillary	74	32	43 2
Brachial	601	159	26 5

TABLE 49

Incidence of gangrene in embolism—this study

Gangrene of digits or more—primary and terminal
(Indeterminate cases excluded)

Site of *embolism*	Number of *incidents*	Incidence of gangrene	
		Number	%
Axillary	10	2	20
Brachial	12	0	0
Common iliac	25	11	44
Common femoral	19	5	26
Popliteal	27	3	11

No doubt the incidence of gangrene following ligation for gun-shot wounds is much higher than could be accounted for by simple occlusion of the main arterial trunk, for these wounds are often complex, with damage to collaterals as well as the main trunk and much complicating sepsis. However, the incidence of gangrene in hospital cases of embolism (Table 49), is also much higher than the overall incidence, for as was shown in Chapter III there are many cases of embolism which never come under observation at all and all recover spontaneously Taking all these facts into consideration, the assertion that arterial ligation carries a much lower risk of gangrene than embolism cannot be sustained

A comparison with the results of surgical ligation does not therefore justify any assumptions as to the occurrence of arterial spasm in embolism

(c) Observations at operations on arteries

The most frequently reiterated argument for arterial spasm is the observation made by many surgeons at operation that the artery distal to an embolus is always greatly narrowed This has often been interpreted as a state of spasmodic contraction (*e.g* by Peiser and by Denk in the passages already quoted). However, an artery must adapt its diameter to the pressure and volume of its contained blood, and these will obviously be reduced immediately distal to an occlusion This is now recognised by a number of authors (*e.g.* Richards (1954), Jepson (1955)). Even when narrowing is seen to extend *proximally* from the embolus, there is one further condition which must be satisfied before the conclusion can be drawn that the narrowing is due to active spasm *It must be proved that there is no separate occlusion of the arterial trunk higher up in the limb* This

requirement is not merely academic, for multiple embolism in a single limb is not uncommon. Twenty examples were observed in the present study

In some of the reported cases of supposed 'proximal arterial spasm', this possibility has not been excluded Burt, Learmonth and Richards (1952) reported a case of apparent spasm in the popliteal artery, thought to result from an embolism of one of its distal branches A man of 56 years with mitral stenosis and auricular fibrillation had acute ischaemic symptoms in both lower limbs, more severe in the left and accompanied at the onset by transient lumbar pain. The pain in the right leg subsided in 30 minutes, and 3 hours after onset the left femoral pulse was absent and the right present. Six hours after onset, signs of ischaemic muscle damage were apparent in the left calf It was concluded that a small embolus had lodged in the left popliteal artery and this was explored. It was '. . . found to be patent but not pulsating. When it was opened, blood flowed from the incision—at first dark and sluggish but soon a brisk non-pulsatile stream of bright red blood'. Exploration of the popliteal artery and the proximal parts of the anterior and posterior tibials revealed no embolus and the incision was closed. The patient recovered from the ischaemic episode and died 6 months later. 'At autopsy, the aortic bifurcation was not occluded, unfortunately the vessels of the lower limb were not examined'. The conclusion that the symptoms were due to spasm set up by a small embolus below the knee does not seem justified. No such embolus was demonstrated and the iliac trunks do not seem to have been examined. The course of events could be explained by an embolus which lodged temporarily at the aortic bifurcation and then moved down into the iliac or femoral. (Indeed, according to the writer's experience the development of acute ischaemic muscle damage in the calf points to a relatively high occlusion)

Atlas (1942) reported the case of a woman of 36 years, suffering from mitral stenosis with auricular fibrillation, who had acute ischaemic syndrome of the right lower limb The popliteal and both foot pulses were absent, while the femoral pulse at the groin was 'excellent' A diagnosis of embolism of the *popliteal* artery was made and this vessel was explored It was found to be '. . markedly constricted, its diameter measuring only $\frac{1}{8}$ inch . . ', and pulsating *very feebly*, but it contained no thrombus *The artery was left intact and the* wound closed. The limb made '. . an excellent anatomical and functional recovery', but the report does not state whether there was any return of the suppressed pulses. Atlas' inference that this was a case of proximal spasm from embolism of the popliteal artery is surely not valid A much more probable explanation is that it was a case of *femoral* embolism and that the exploration, made distal to the occlusion, revealed the usual collapsed vessel.

Objections of this sort can be made to many other cases similarly interpreted, for example those of Åkesson (1937) and Seifert (1931). (Seifert's case has been quoted by other writers as an instance of arterial spasm, though he did not himself interpret it in this way)

Delay in return of pulses after embolectomy has been regarded as evidence of arterial spasm (Richards (1954)). This may well be correct, but as the arterial wall in such cases has been injured by arteriotomy any spasm which occurs may be traumatic.

When critically examined with these considerations in mind, much of the evidence provided by observations at operation can therefore be called in question.

(d) Clinical evolution of ischaemic symptoms and signs

Some authors (*e g*. Leriche) have suggested that the intense pallor often seen in a limb soon after embolism is itself evidence of active spasmodic constriction of the arterial system and that when the pallor is replaced by cyanosis this means that the spasm has relaxed. This assumption is not justified. If the blood supply of a limb be suddenly cut off by occlusion of the main arterial trunk, the fall of blood-pressure in the arterioles must inevitably result in pallor of the skin. The same phenomenon is seen in the face during a syncopal attack, when the blood-pressure suddenly falls as a result of cardiac slowing. The collateral arteries must dilate by relaxation of their normal sympathetic vasomotor tone before the collateral circulation can develop fully and produce some colour in the limb. If collateral circulation remains inadequate, pallor will persist in the extremity of the limb.

Variation in severity of the ischaemia from embolism of the same artery in different patients has been interpreted as due to variation in the intensity of arterial spasm (*e g*. by Atlas, quoted above). This assumes that the number and size of arterial collaterals must be similar in all persons, but the evidence presented in Chapter IX does not support the assumption. The anatomical variations in arterial collaterals could explain varying degrees of ischaemia.

In Chapter III it was shown that many cases of limb embolism recover rapidly without treatment. This fact in itself conflicts with the view that serious arterial spasm is common

Richards (1954) pointed out that the presence of an old embolism in a limb may mitigate the effects of a subsequent embolism· 'It therefore appears that the presence of a previous arterial occlusion helps to protect the limb from the effects of an acute ischaemia produced by a more proximal obstruction.' This statement is perhaps a little too sweeping The effect probably depends upon the anatomical relation between the two occlusions and there are some cases in which a prior embolism may *aggravate* the effects of a subsequent one (*e g* Cases Nos. 69 (R upper limb) and 76). However, there are undoubtedly cases in which the protective effect occurs, *e.g*. Case No. 50. This patient recovered well from the effects of an embolism of the left common iliac artery. Sixteen months later she had embolism of the aorta and on this occasion the effects in the previously embolised left limb were trivial but in the right limb gangrene

rapidly ensued The survival of the left limb was probably due to the degree of development of its collateral arteries, stimulated by the earlier occlusion. If the grave ischaemia in the right limb had been in any way due to arterial spasm, the left limb could hardly have escaped its effects in this way, for the embolus was in the aorta and arterial spasm, if present, should have affected both limbs. The main difference between the two limbs appears to have been anatomical and this was reflected in their respective fates.

None of the phenomena mentioned in this section affords any real evidence of arterial spasm

(e) Extent of the ischaemic signs in limb embolism

De Takats (1942) and Holden (1952), already quoted, stated that the extent of the ischaemia in limb embolism may be so great as to give a false impression of the height of the obstruction Leriche (1947) made a similar assertion:

> This vasoconstriction extends both distally and proximally, at least in many cases. It is not uncommon to find the whole limb livid and pale when the embolism is, for example, in the region of Hunter's canal Thus the vasoconstriction is widespread and complete

Other surgeons, *e g.* Perman (1927), have stated on the contrary that the proximal limit of the ischaemic signs is usually a good deal distal to the point of occlusion Haimovici (1937) also stressed this principle and quoted a number of authors whose experience concurred (Petitpierre (1928), Sencert (1923), Key (1922), Bull (1921))

The extent of ischaemic skin signs, *i e.* colour change (pallor or cyanosis) and objective coldness, was recorded in a number of anatomically verified embolic occlusions, all seen within 24 hours of onset. The findings confirm the view of Perman rather than that expressed by De Takats, by Holden and by Leriche They are shown in Table 50 and in Fig. 23, and there was not a single instance in which the ischaemic signs extended to a level as high as the site of the embolus

The usual extent of ischaemic signs in the writer's experience therefore serves as evidence *against* arterial spasm rather than in favour of it.

(f) Embolic migration

An embolus is sometimes observed to lodge for a time in a large artery and then to move into a more distal vessel. This has been interpreted by Leriche as evidence that the embolus is at first held by spasmodic contraction, excited by its impact in the artery, and that after an interval this spasm relaxes and allows the embolus to move further.

In the present study this phenomenon was observed on three occasions only and in every case the migration was from the lower aorta into the common iliac

TABLE 50

Level of upper limit of ischaemic skin signs

19 cases of lower limb embolism all anatomically verified
(Observed within 24 hours of onset)

Site of embolism	Position of upper limit of ischaemic signs	Number of cases
Common iliac (8 cases)	Above inguinal ligament	—
	Between inguinal ligament and mid-thigh	2
	Between mid-thigh and knee	4
	Between knee and ankle	2
	Total	8
Common femoral (7 cases)	Above knee	—
	Between knee and ankle	4
	Not above ankle	3
	Total	7
Popliteal (4 cases)	Above mid-tibia	2
	Between mid-tibia and ankle	1
	Below ankle	1
	Total	4

(The actual levels observed in these 19 cases are represented diagrammatically in Fig 23)

artery (Cases Nos 7, 8, 65). (There was one other case in which a similar migration probably occurred before the patient was admitted to hospital (Case No. 21).) The fact that migration occurs mainly in the largest of the limb arteries suggests that it may be due merely to a process of moulding. Many arterial emboli are thrombi of very recent formation, quite soft in consistency (Chapter V), and under the impact of the powerful aortic pulsation a soft thrombus might be gradually forced from the aorta into the common iliac artery. Indeed, when an embolised artery is exposed at operation, the embolus is sometimes visible through the arterial wall, moving slightly like a piston with each pulsation of the vessel (Cases Nos 7 and 8). Further, the development of collateral circulation, by increasing blood-flow into the main trunk beyond the occlusion, will

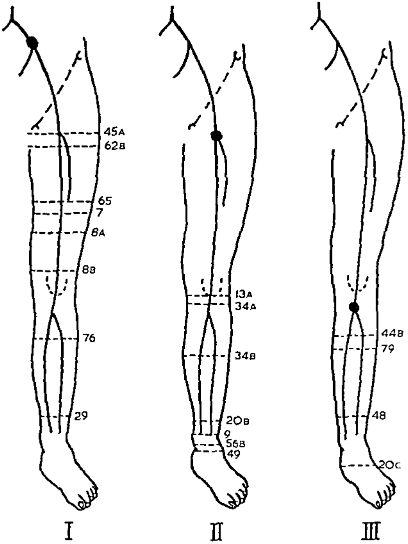


FIG 23 *Extent of ischaemic signs in lower limb embolism* The diagram shows the levels of the upper limit of ischaemic skin signs (pallor, cyanosis or objective coldness) in 19 cases of lower limb embolism, all seen within 24 hours of onset, all anatomically verified

I 8 cases of embolism of the common iliac artery
II 7 cases of embolism of the common femoral artery
III 4 cases of embolism of the popliteal artery

The numbers indicated are those of the case records in the Appendix. Where a letter (A, B or C) follows the number, this indicates one incident of limb embolism in a patient who had multiple incidents. (See p. 131)

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Level of upper limit of ischaemic skin signs

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	Between mid-thigh and knee	4
	Between knee and ankle	2
	Total	8
Common femoral (7 cases)	Above knee	—
	Between knee and ankle	4
	Not above ankle	3
	Total	7
Popliteal (4 cases)	Above mid-tibia	2
	Between mid-tibia and ankle	1
	Below ankle	1
	Total	4

(The actual levels observed in these 19 cases are represented diagrammatically in Fig 23.)

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TABLE 51

Incidence, site and timing of pain in peripheral embolism

118 embolic incidents ('pseudo embolism' excluded)

History of transient pain at or about site of embolus, succeeded by more distal pain	10 incidents
History of transient pain at or about site of embolus, without any distal pain	1 incident
History of distal pain only	56 incidents
All incidents with history of pain:	67 incidents
No pain at any time	10 incidents
No information as to pain	41 incidents
Total	118 incidents

incidents giving a history of pain there were only 11 instances of 'arterial pain'. These were in 5 instances of aortic embolism, 5 of iliac embolism and one of axillary embolism. From this experience it would appear that 'arterial pain' is relatively uncommon and that it occurs in embolism of the largest arterial trunks, particularly the aorta and the common iliac. These arteries have one character in common which distinguishes them from more distal arteries of the limbs: they all supply branches to some part of the torso as well as to the limb. Occlusion of such branches by an embolus in the parent trunk might produce ischaemic pain in sites other than the periphery of the limb.

The instances of 'arterial pain' recorded in this study were almost all fleeting in character, and if they be evidence of arterial spasm then they indicate that this is uncommon and transient. In aortic embolism the 'arterial pain' is usually felt in the lower abdomen or the lumbar region. It may well be ischaemic pain, caused by occlusion of certain branches of the lower aorta, *e.g.* the inferior mesenteric, and there is no certainty that it really is arterial pain. In the writer's experience, intensity and extent of pain in limb embolism are related mainly to the gravity of the ischaemia.

It must be concluded that the character and site of the pain in limb embolism do not form any very sound basis for the theory of embolic arteriospasm.

(h) Effect of sympathetic ganglion block and vasodilator drugs

Stricker and Orban (1930) showed that in dogs the massive gangrene of the hind limbs produced by resection of the aortic bifurcation could be prevented by prior lumbar sympathectomy. Leriche, Froment and Vachon (1934) treated a case of femoral embolism by arteriectomy, and on the day after operation they

increase the diameter of this trunk again and so facilitate migration of the embolus. (A similar phenomenon in experimental embolism, noted many years ago by Ebbecke (1923), is discussed in Section (*k*) of this chapter.)

The occasionally observed *instances of embolic migration can therefore be* explained without invoking the effect of arterial spasm.

(g) Character and site of pain in limb embolism

Many authors have suggested that pain in limb embolism may be an expression of 'arterial cramp' or spasmodic contraction of the vessel at the site of impaction of the embolus (Allen, Barker and Hines (1955), already quoted, Leriche (1947), Graham (1937), Seifert (1931)). *Two types of pain have been* described. (1) an initial pain, localised to the site of impaction and usually transient, which we may term 'arterial pain', followed after an interval by (2) a continuous pain situated within the area of ischaemic signs, which, as was concluded in Section (*e*) of this chapter, is always distal to the site of the embolus. This second type of pain may be termed 'ischaemic pain' Allen, Barker and Hines (1955), in the passage already quoted, thought that the initial pain is caused by arterial spasm. Lewis (1936) produced evidence to show that the pain in embolism is usually confined to the more distal area of the ischaemic signs In Lewis' view, the pain originates in muscle tissue, injured by the metabolic effects of a depleted circulation.

Lewis also pointed out that when the main artery of a resting human limb is obstructed by pressure, an interval of 30–40 minutes often elapses before the onset of pain. If the limb is being exercised at the time of the arterial obstruction, the pain comes on more quickly.

These two considerations are of importance in relation to the pain of arterial embolism. Firstly, as indicated in Sections (*c*) and (*i*) of this chapter and as already discussed in Chapter VII, it is possible to be mistaken as to the site of an embolus When there *is a major error of localisation it* is usually a 'distal error', *i e.* the embolus is thought to lie more distally than it actually does. Reference of the site of a pain to the site of impaction of an embolus is therefore liable to error, and pain which is regarded as arterial pain may in fact sometimes be ischaemic pain.

Secondly, it cannot be assumed that the moment of onset of the pain coincides with the moment of impaction of the embolus, and the assumption that pain is 'immediate' or 'initial' pain may therefore be unfounded. For these reasons, the conclusions of some writers about 'arterial pain' may well be fallacious However, there are some authors with much personal experience of embolism who are of opinion that in some cases there is a true initial arterial pain, *excited at the site of impaction of* the embolus (Richards (1954)).

The incidence, site and timing of pain in the embolic incidents of this study have been analysed and the findings are shown in Table 51. Among 67 embolic

established varieties of arterial spasm are associated with some lesion of the arterial wall, either traumatic or inflammatory, and embolism, thrombosis or haemorrhage in the wall of an artery might well act in a similar way.

Some observers have explained cases of pseudo-embolism by assuming that a small embolus, lodging in one of the distal branches of a limb artery, has set up a widespread state of arterial spasm, extending proximally along the main trunk, into the collateral vessels and even into the arteries of the opposite limb. A case interpreted in this way by Burt, Learmonth and Richards has already been mentioned. Atlas (1942) reported the case of a woman of 37 years, suffering from mitral stenosis with auricular fibrillation, who developed acute ischaemic syndrome, first in the left lower limb and 30 minutes later in the right. She was examined soon afterwards and all pulses were found to be absent in both limbs. Following conservative treatment, all pulses returned in the right limb within 72 hours and good pulses returned in the left femoral and popliteal arteries within 2 weeks (presumably no pulses returned in the left foot). Atlas interpreted this observation as a case of widespread bilateral arterial spasm resulting from the impaction of an embolus at the left popliteal bifurcation. The patient died of cerebral embolism some months later, but there appears to have been no autopsy and this interpretation was therefore not tested.

Unverified observations of this sort afford no proof of embolic arteriospasm. The case may have been one of pseudo-embolism of the aortic bifurcation, but there is no evidence to suggest that it was provoked by the left popliteal occlusion, which could easily have been present for weeks or months. Without more information no firm conclusions can be drawn as to the causation of this interesting clinical observation.

There is no doubt of the reality of the condition which, for want of a better term, must be called ' pseudo-embolism ', and it seems very likely that it is due to arterial spasm. However, pseudo-embolism cannot be invoked as evidence of *embolic* arteriospasm, for by definition the characteristic feature is the *absence* of any embolus in the arterial lumen.

(j) Pulse deficiencies proximal to the site of an embolus

As mentioned in Section (*c*) of this chapter, cases have been described in which arterial pulses were absent at points considered to be proximal to the site of the embolus. Some of these instances are open to doubt because it has not been proved by full exploration of the arteries exactly where the embolus or emboli were situated. Nevertheless, there are instances in which pulses may be suppressed at some point proximal to the site of an embolus, and this would seem to point to the existence of arterial spasm, at least in the main trunk of the vessel.

There were 40 embolic incidents in which the site of the embolus was anatomically verified and which were all seen within 7 days of onset. Analysis

thought that novocaine infiltration of the lumbar sympathetic ganglia produced improvement in the ischaemic signs. Many of the French observers hold that arterial embolism excites reflex vasospasm, mediated through the sympathetic nerve supply of the limb, and that blocking of the sympathetic ganglia counteracts this injurious reflex. Any improvement in the ischaemic signs observed after this treatment has been held to confirm the presence of arterial spasm.

Denk (1934) described the results of treatment of limb embolism by intravenous injection of papaverine ('Eupaverin'), given for its vasodilator effect. *In a number of cases he noted amelioration of the ischaemic signs soon after the* injections were begun. De Takats (1936) reported similar observations. This improvement following the use of vasodilator drugs has also been regarded as evidence of embolic arteriospasm:

> I could imagine no finer confirmation of the explanation of the acute ischaemic effects produced by embolism which I gave twenty years ago. *Leriche* (1947)

An improvement in ischaemic signs observed shortly after the administration of vasodilator drugs (or any other treatment) cannot always be ascribed to the treatment. Similar improvement may sometimes be observed to occur spontaneously (especially in cases examined very soon after onset), and many cases of embolism give a history of rapid improvement, occurring before the case comes under observation. *Claims made for various methods of treatment have not* always been tempered by an understanding of the possibilities of natural recovery. Even in recent years some authors have stated that gangrene is almost inevitable in untreated embolism of the larger limb arteries (Leriche (1947), Handfield-Jones and Porritt (1951)). Consequently, when improvement or recovery is observed there is a tendency to attribute it to the treatment given, though this may not always be justified.

However, even if improvement in ischaemic signs is sometimes brought about, for example by infiltration of the sympathetic ganglia, this is not necessarily evidence of any active state of arterial spasm *In a normal person, dermal* vasodilatation in the extremity may follow blocking of the sympathetic ganglia, but this does not prove that the limb arteries were in a state of abnormal spasm before the injection. The effect is attributable to suppression of the normal sympathetic vasoconstrictor tone. *The same explanation can be given for an* improvement in circulation produced by similar means in an embolised limb.

(i) Pseudo-embolism ('fausse embolie')

Pseudo-embolism has already been mentioned in Chapter VII. A condition of arterial spasm *seems to account for at least some of these cases,* though the mechanism of its causation is obscure. Leriche thought it might be due to micro-embolism in the adventitial vessels or the vasa vasorum. Most of the



FIG 24 (*Case No 78*) Embolism of right superficial femoral and left popliteal arteries Arteriography (intra-vitam, about two months after the acute ischaemic symptoms) Technique 20 ml ' Pyelosil 70% ' injected into abdominal aorta

On the left side the common femoral, superficial femoral and deep femoral arteries are all visualised, on the right side the common femoral and deep femoral only On the right side the embolus occluded the mouth of the superficial femoral, on the left side it was situated at the lower end of the popliteal, which is not included in the photograph

of these reveals two cases in which pulse deficiencies were observed at points proximal to the site of the embolus. In both cases the site of the embolus was precisely determined later at autopsy and a full examination was made of the limb arteries, proving in each case that there was no additional occlusion, complete or partial, higher up in the limb.

Case No 9 was a man of 55 years, suffering from bacterial endocarditis, who had embolism of the right common femoral artery. When he was examined next day, the right femoral pulse at the groin, above the site of the embolus, was definitely weakened as compared with the left, though never completely suppressed (The embolus was a septic one and may therefore have excited an inflammatory reaction in the wall of the artery.) The collateral circulation in the affected limb remained good for 7 days but deteriorated 3 days before death (' terminal gangrene ').

Case No. 78 was a woman of 66 years, suffering from auricular fibrillation, who had embolism of the left popliteal artery. When she was first examined, 3 days after onset, both the femoral and popliteal pulses were absent on the left side, but the ischaemic signs were only of moderate severity and rapidly subsided. The femoral pulse returned 10 days and the popliteal pulse 18 days after onset. Arteriography 10 weeks later, when all ischaemic signs had disappeared, showed patency and normal calibre of the arterial trunk down to the level of the upper popliteal (Fig 24), and the embolus (an aseptic one) was later proved at autopsy to be at the bifurcation of the popliteal. The patient had a further embolism after admission to hospital, in the right femoral, but on this occasion there were no anomalous pulse deficiencies.

These two cases, and particularly Case 78, thus showed clinical evidence of spasm in the affected arterial trunk, excited by an embolus and extending proximally from its site of impaction. In both cases the ischaemic signs were mild (though in Case 9 they became worse again 7 days later, just before death) and the upper limit of the ischaemic signs was well distal to the actual site of the embolus. If arterial spasm was present, which seems inescapable, it certainly had little effect on collateral vessels.

A number of writers claim to have observed cases of embolism in which ischaemic signs and pulse deficiencies have not only extended up the limb proximal to the site of the embolus, but have also involved the opposite limb (*e.g.* Atlas (1942); Burt, Learmonth and Richards (1952)). If the three examples of embolic migration be excepted, no case was observed in this study in which ischaemic symptoms or signs in one limb have been proved to be due to an embolic occlusion in the opposite limb. In case No. 78, referred to above, an embolus at the left popliteal bifurcation seems to have produced pulse deficiencies (though not ischaemic signs) as far proximally as the groin, but it produced no effects on the opposite limb. In the writer's view, this theory of ' contralateral ischaemia ' should not be accepted as an explanation of any

sion of the main mesenteric artery its arterioles decreased very much in diameter. This would seem to be an inevitable result of the fall in local blood-pressure produced by the occlusion, but these authors interpreted the narrowing as due to spasm When the occlusion of the main mesenteric artery was released the arteriolar narrowing persisted for some time and this was regarded as further evidence of a state of spasm in the arterioles. However, in the experiments the mesenteric artery was occluded by mechanical means and the possibility of injury to the arterial wall does not seem to have been excluded Any arterial spasm observed may have been due to trauma.

Experiments of this kind have sometimes been quoted in discussions of embolic arteriospasm, but they do not appear to have much relevance.

(m) Distension experiments on animal arteries

Malmejac and Haimovici (1935) carried out a series of experiments on the effects of occlusion and distension of the iliac artery in dogs They used a sac, constructed from an excised segment of jugular vein and inverted so as to present its intimal surface externally The sac was introduced into the iliac artery, and it could be distended by injection of saline into its interior through a tied-in tube. The only surface in contact with the arterial intima thus consisted of venous endothelium, and this was considered to obviate the factor of irritation of the arterial intima by the introduction of foreign material

The aim of the experiments was to observe reflex vasomotor reactions in the distal part of the limb when the iliac artery was occluded or distended. In order to avoid the effects of depletion of blood-flow into the distal arteries when the iliac artery was occluded, recourse was had to the method of ' patte irriguée ' (Delezenne (1897)). The iliac artery was severed and ligated distal to the occluding sac and the whole of the tissues of the thigh, with the exception of the three main nervous trunks (sciatic, femoral and obturator) were completely divided. The circulation of the severed distal portion of the limb was maintained by independent perfusion from the circulation of a second dog, the femoral artery and vein being joined to the carotid and internal jugular vessels of the latter animal The severed limb, thus isolated from its parent body except for its three main nervous trunks, was enclosed in a plethysmograph for study of the reflex vasomotor reactions produced by manipulation of the sac occluding the iliac artery.

By the use of this method, a number of observations were made, chief among them being the following.

(i) Slow and gentle occlusion of the iliac artery, without distension, produced no vasomotor response in the vessels of the perfused limb.

(ii) Distension of the iliac artery by steadily increasing the pressure in the occluding sac, if violent (' brutale '), produced a slight and transient vasoconstriction in the perfused limb

clinical phenomena unless there has been a complete anatomical examination of all the arteries of both limbs.

The two cases here described represent the sum total of clinical evidence of embolic arteriospasm in the writer's experience. In both of them the evidence indicates that there was arterial spasm, but it was confined to the arterial trunk and seemed to be quite innocuous.

2. EXPERIMENTAL OBSERVATIONS

(k) Experimental embolism

Ebbecke (1923) made experimental observations on artificial embolism in frogs, using the method devised by Cohnheim (1872) Minute granules of wax, coloured with lamp-black, were injected into the arterial circulation and the process of arteriolar embolism was directly observed microscopically in the vessels of the tongue It was noted that the granules were held temporarily in the small vessels in which they became impacted, but that after an interval these vessels appeared to relax and allow the granules to pass further. It is not stated whether the arteriolar narrowing extended proximally from the impacted granules Ebbecke's observation is open to the same interpretation as that given in Section (c) of this chapter for observations at operation The subsequent dilatation of the vessel, which allowed the granule to pass on, can be explained by a rise in its internal pressure due to inflow from collateral vessels, perhaps aided by ischaemic vasodilatation (Chapter XI—discussion on ' reactive hyperaemia ').

Furthermore, the reaction of an artery to the introduction of a foreign substance, possibly irritating to its intima, is not necessarily the same as its reaction to impaction of a blood-clot.

(l) Ligation experiments on animal arteries

Mulvihill and Harvey (1931) ligated the external iliac artery in dogs and found that this caused a temporary decrease in the surface temperature of the corresponding paw. The return to normal temperature could be accelerated by removal of the tributary sympathetic ganglia and the fall of temperature could be altogether prevented if these ganglia were removed at the time of ligation of the artery These authors concluded that re-establishment of circulation through collateral arteries must be a vasomotor phenomenon. Some writers have argued that if the collateral circulation is established by vasodilatation there must have been a prior state of spasm in the collateral arteries This assumption is not necessary. The observations can be explained by inhibition of the normal sympathetic vasoconstrictor tone and do not necessarily indicate any state of abnormal vasospasm.

Laufman, Martin and Tuell (1948) observed the vessels of the dog's mesentery by direct micro-photography of the arterioles. They noted that after occlu-

Unless these objections can be satisfactorily answered, the experiments cannot be accepted as evidence of reflex vasoconstriction in human embolism.

Conclusions

1. The theory that embolism often sets up a state of active spasmodic contraction in the main trunk and branches of the occluded artery and in the collateral arteries upon which the circulation of the limb depends should not be accepted without convincing evidence

2. Most of the evidence, both clinical and experimental, on which the theory has been based is open to serious objection.

3. Occasional cases of embolism are seen in which there is clinical evidence of spasm in the occluded main arterial trunk, but even in these cases there is no evidence that such spasm involves the collateral arteries or aggravates the ischaemia.

4. It must be concluded that arterial spasm is not an important factor in the genesis of ischaemia and that its role has been much exaggerated.

(iii) 'Violent' intermittent distension of the iliac artery produced in the perfused limb a vasoconstriction lasting as long as the 'violence' was maintained and ceasing soon after it was discontinued.

Malmejac and Haimovici concluded from these experiments that a stimulus of intermittent distension of an arterial trunk could cause reflex vasoconstriction in the distal field of ramification of the artery, mediated through spinal centres and lumbar sympathetic system, and they inferred that embolism of the arterial trunk might act in a similar way To this inference certain objections can be made:

(i) In the experiment an intermittent distending pressure of '25–30 cm of mercury or even more' was required to produce distal vasoconstriction in the perfused limb. This is approximately double the normal carotid blood-pressure of the dog Though embolic occlusion of a large arterial trunk may cause a moderate rise of blood-pressure (Chapter VI) and does appear sometimes to increase the force of the pulsation in the arterial segment proximal to the embolus, it does not seem credible that it could produce any distending stimulus so violent *as that required in the experiment*

(ii) The vasoconstriction recorded plethysmographically in the perfused limb could have been produced purely in the small distal vessels and there is no proof that the arterial trunk or its collaterals were involved This is not a purely hypothetical objection, for Kinmonth (1952) showed that electrical stimulation of the femoral artery in the rabbit has no effect on the upper third of the artery but causes profound vasoconstriction in the distal part. Kinmonth also showed *that electrical* stimulation of the lumbar sympathetic chain had no effect on the upper third of the femoral artery, though it did cause shrinking of the paw, and that intravenous injection of adrenaline caused contraction only of the lower part of the femoral artery, the upper part actually dilating in response to the rise of general blood-pressure resulting from the injection. If embolism were to produce vasoconstriction in the distal field of ramification of the occluded artery, *this would of course be* just as serious a factor in aggravating ischaemia as constriction of the proximal collateral vessels. However, Kinmonth's observations were made upon unoccluded arteries and they do not show what would happen in a limb made ischaemic by occlusion of its main artery. In such a limb, the factor of ischaemic vascular relaxation (Chapter XI) might well modify these reactions. The same considerations must apply to the *vasoconstriction observed in the experiments of* Malmejac and Haimovici.

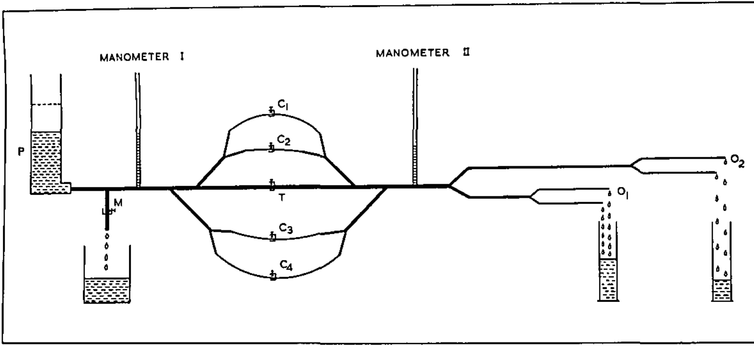


FIG 25 *Diagram of model 'limb circulation'* (*See Chapter VI.*)

The model was constructed of rubber tubing with glass connections In operation the whole of the tube system (represented in black) was placed in the horizontal plane.

'P'—Water supply reservoir (hydrostatic pressure of water recorded as 'P')
'M'—Branch representing general circulation (internal diameter 4·25 mm)
'T'—Main trunk of 'limb system' (internal diameter 4·25 mm)
'C_1, C_2, C_3, C_4'—Collaterals of 'limb system' (internal diameter· 1·0 mm each)
'O_1'—Proximal exit tubes (internal diameter· 1·0 mm each)
'O_2'—Distal exit tubes (internal diameter 1·0 mm each)

XI

The Genesis of Ischaemia in Embolism

SOME PHYSICAL PRINCIPLES

Some of the physical principles governing the flow of a liquid through an elongated branching system of tubes can be empirically illustrated by a simple model One is shown diagrammatically in Fig. 25.

The model was constructed of rubber tubing with glass connections, water being allowed to flow through the system from a supply reservoir. The large side-branch 'M' represented the general circulation and the flow through this was controlled by a screw-clamp. The rest of the system represented the arterial system of a limb, with the main trunk 'T', four collaterals 'C_1', 'C_2', 'C_3', 'C_4', a short exit system 'O_1' and a long exit system 'O_2'. The trunk and all the collaterals could be closed by screw-clamps and there were manometers 'M_1' and 'M_2' to indicate the hydrostatic pressure in the trunk, proximal and distal to the collateral system. The main trunk 'T' and the side-branch 'M' each had an internal diameter of 4·25 mm (cross-sectional area 14·2 sq mm) The four collaterals and the four exit tubes each had an internal diameter of 1·0 mm (cross-sectional area 0·8 sq. mm). In operation, the whole system of tubes was placed in the horizontal plane

Observation was made of the varying rates of outflow of water at O_1 and O_2 with the whole system open and with various combinations of closure of the different channels T, C_1, C_2, C_3 and C_4 The conditions could also be further modified by varying the hydrostatic pressure 'P' in the supply reservoir and by increasing or decreasing the flow through the side-branch M Some of the findings are given in the following records (The figures are the means of repeated observations, which showed very little variation.)

CIRCULATION MODEL

Experiment (3)

Main trunk closed. Effect of diversion from 'limb system'.

Pressure at 'P' (cm H_2O)	Pressure at 'M_1' (cm H_2O)	Trunk (open or closed)	Number of collaterals open	Pressure at 'M_2' (cm H_2O)	Outflow at 'O_1' (ml p/M)	Outflow at 'O_2' (ml p/M)
10	10	Closed	3	6·9	8·8	4·2
'M' opened further, considerably increasing its flow:						
10	8·7	Closed	3	6·2	7·0	3·2
'M' opened still further·						
10	7·5	Closed	3	5·6	5·6	2·6
One collateral closed						
10	8·4	Closed	2	5·3	5·0	1·6
Perfusion pressure ('P') increased by 50%						
15	12·6	Closed	2	6·9	8·4	4·0

The main principles demonstrated by these experiments may be summarised as follows:

1. Outflow at the distal exit was much less than that at the proximal exit.
2. So long as the main trunk remained open, the opening or closure of several small collaterals had no significant effect on pressures or outflow figures.
3. With the main trunk closed, when the available collateral channels were reduced to one (with cross-sectional area about $\frac{1}{17}$ of that of the trunk), the distal outflow almost ceased, while the proximal outflow continued, though at reduced rate. The opening of 3 additional collaterals of similar size increased the outflow considerably. This increase was proportionately greater at the distal exit.
4. A diversion of flow from the 'limb system' by reduction of resistance in the 'general circulation' reduced the distal outflow in the limb system considerably.

Experiment (1)

Main trunk open. (*a*) Effect of opening collaterals.
(*b*) Effect of varying perfusion pressure.

Pressure at 'P' (cm H_2O)	Pressure at 'M_1' (cm H_2O)	State of Trunk	Number of collaterals open	Pressure at 'M_2' (cm H_2O)	Outflow at 'O_1' (ml p/M)	Outflow at 'O_2' (ml p/M)
10 0	10 0	Open	0	9 7	17 0	7·0
10 0	10 0	Open	4	9 7	17·0	7 0
15·0	14·5	Open	0	13·5	23·4	11·8
15 0	14·5	Open	4	13·5	23 6	11·8
22 5	21·2	Open	0	19·4	35·0	23·6
22 5	21·2	Open	4	19·5	35·8	23·4

CIRCULATION MODEL

Experiment (2)

Main trunk closed. Effect of variation of number of collaterals open.

Pressure at 'P' (cm H_2O)	Pressure at 'M_1' (cm H_2O)	Trunk (open or closed)	Number of collaterals open	Pressure at 'M_2' (cm H_2O)	Outflow at 'O_1' (ml p/M)	Outflow at 'O_2' (ml p/M)
10	10	Closed	1	5 0	5 6	0 6
15	15	Closed	1	5·8	7·6	2·2
10	10	Closed	2	6·2	7 8	2 4
15	15	Closed	2	7·8	11·2	4·8
10	10	Closed	3	6·9	9·6	3 8
15	15	Closed	3	9·5	13·0	7 2
10	10	Closed	4	7·8	9 0	4 8
15	15	Closed	4	10·3	14·4	8 6

held to account for the well-known phenomenon of 'reactive hyperaemia' When the arterial supply of a limb is restored after temporary interruption, the return of blood produces an immediate flushing of the whole limb, presumably because the vessels have become completely relaxed during the period of ischaemia.

The only available method of demonstrating ischaemic vascular relaxation —by restoring full blood-flow to the limb—is not usually possible in a limb with an embolic occlusion of the main arterial trunk. If the embolus were to migrate into a side-branch, thus suddenly restoring the flow into the main trunk, reactive hyperaemia should occur However, embolic migration is not a common occurrence and the opportunity of observing the limb at the appropriate moment is rarely granted. One incident observed in this study may have been an example of this phenomenon. Case No. 77 was a woman of 66 years, suffering from mitral stenosis and auricular fibrillation, who had already had embolism of both popliteal arteries. She subsequently had a slight cerebral embolism and was examined about 30 minutes after the onset of the cerebral symptoms In addition to the hemiparesis there were signs of pronounced ischaemia of the left upper limb, with absence of the radial pulse While the brachial artery was being palpated, the radial pulse suddenly returned and a typical reactive hyperaemia immediately appeared in the hand It was suggested in Chapter VII that this may have been an example of embolic migration (p 68), but whether this be true or not the observation certainly suggested the presence of vascular relaxation in an ischaemic limb.

Linell and Piercy (1949) reported two similar observations, in which manipulation of an embolus through the wall of an exposed artery produced sudden improvement in the circulation of the limb, with reactive hyperaemia. They interpreted this as due to fragmentation and migration of the embolus. Piercy (1957) carried out a similar manoeuvre in one further case by firm external massage over the brachial artery in an intact embolised limb, and in this case also he observed flushing of the limb

The clinical observations described in Chapter VI and Chapter VIII indicated that when collateral circulation is adequate, that fact is evident within two hours of the onset of symptoms This is in harmony with the results of some experimental work on the establishment of collateral circulation. Eckstein, Gregg and Pritchard (1941) found that when the femoral artery was occluded in dogs, the collateral circulation, as measured by the backflow pressure in the arterial trunk distal to the occlusion, was established very rapidly, often reaching half the normal inflow within 90 minutes.

If the vascular system of an embolised limb is in a state of relaxation, this rapid establishment of collateral circulation is readily understood. Though the relaxation may not directly involve the main collaterals of the occluded arterial trunk, which would usually be some distance from the ischaemic area, yet it

5. In all conditions of the system, a moderate increase in perfusion pressure *produced a considerable increase in outflow, both proximally and distally*. This effect was proportionately greater at the distal exit.

It is not suggested that the conditions in a simple system of this kind fully represent those in the complex vascular structure of the human limb. Nevertheless, the principles enumerated above must continue to operate. In fact, some post-mortem perfusion experiments on human limbs gave parallel results for the differences in outflow at different points along the limb and for the effects of variation of the perfusion pressure. Some of the post-mortem arteriographies illustrated 'diversion' effects (when an alternative path was available) not unlike those shown by the model. The model illustrates the action of two factors of great importance in any consideration of collateral circulation:

1. The influence of the number and size of the available collateral channels.
2. The decline of effective perfusion pressure towards the extremity of the system.

In a living limb with an occlusion of the main arterial trunk, apart from the effect of variations in blood viscosity, we have to envisage the influence of motor changes in the vascular system of the affected limb and that of physiological function in the general circulation. The former will affect the conditions of perfusion in the limb itself, the latter will affect the perfusion pressure in the collateral arteries.

Local physiological factors

Theoretical discussion of the effects of embolism has been much influenced by the theory of embolic arteriospasm. In Chapter X, the validity of this theory has been questioned. Direct information on the state of vascular tone in an embolised limb is difficult to acquire. The methods used for demonstrating vasomotor changes, for example plethysmography or capillary microscopy, depend upon a free flow of blood into the limb under investigation and are therefore not applicable.

The majority of writers have concerned themselves with the possibility of active vasoconstriction in the limb and have given little attention to an entirely opposite conception—that of vascular relaxation in ischaemic tissues. This phenomenon was demonstrated by Cohnheim (1872) in his classical experiments on embolism and was discussed at length by Bier (1897 and 1898) and by Hess (1921) in their writings on the mechanism of collateral circulation. There is ample evidence to show that the vascular system of an ischaemic area is normally in a state of 'potential vasodilatation', with all its elements completely relaxed. According to the theory of Lewis (1936), now widely accepted, this is caused by the accumulation of vasodilator metabolites in ischaemic tissues, and it is

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structure in determining the degree of ischaemia and the adequacy of collateral circulation in embolism:

1. The limb survival rate is inversely proportional to the size of the occluded artery (Chapter VIII)
2. Post-mortem arteriography shows that there are some persons with anatomical deficiency of arterial collaterals, especially in lower limbs. The findings are consistent with the limb survival rates in limb embolism (Chapter IX)
3. Post-mortem arteriography shows that the system of arterial collaterals is usually symmetrical. In the majority of cases of bilateral lower limb embolism, the fate of the two limbs is correspondingly similar (Chapters VIII and IX).
4. The ischaemic effects of an embolic occlusion are sometimes mitigated by the presence of an earlier occlusion in the same limb (Chapters VIII and X). This appears to have an anatomical explanation
5. The extent of consecutive thrombosis appears to be determined mainly by anatomical factors and does not itself greatly influence the local result in an embolised limb (Chapter V).
6. When an acute arterial occlusion produces gangrene in a lower limb, the demarcation line very commonly has a characteristic conformation, extending to its highest level on the anterolateral aspect of the leg (Cases Nos 20, 34, 41, 47, 55, 76) This suggests that the area of necrosis is determined by the anatomical structure of the arterial supply.
7. No difference in outcome can be shown between medically treated and untreated embolic occlusions (Chapter VIII) This is explained if the result is determined more by anatomical structure than by local physiological reactions.

In the circulation model, when the main trunk was closed, four collaterals with an aggregate cross-sectional area less than one-quarter of that of the main trunk could produce an outflow at the distal exit equal to two-thirds of that produced when the main trunk was open The volume of collateral blood-flow which can be carried by a system of quite small collateral arteries is equally surprising For example, the collateral circulation of an occluded aortic bifurcation seems to depend mainly upon the following routes:

1. Internal mammary—superior epigastric—inferior epigastric—external iliac.
2. Subcostal—super[illegible] epigastric—external iliac.
3. Lumbar—il[illegible]
4. [illegible]
5. [illegible]
6. [illegible] ernal iliac.

will decrease resistance to blood-flow from these collaterals into the vessels of the ischaemic area. The occlusion in the main arterial trunk causes an immediate fall of blood-pressure in the arteries distal to the occlusion, thereby increasing the pressure differential between these vessels and the collateral arteries. These two factors will encourage blood-flow from the collaterals into the ischaemic tissues Finally, there may be some increase in general arterial blood-pressure, and this will favour the process.

Vascular relaxation would also cause conditions in the arterial system of the ischaemic limb to approximate more closely to those in an inert system of tubes, allowing the principles demonstrated by the model to assert themselves more fully. The adequacy of collateral circulation would then be governed largely by the number and size of the available collateral channels and the greatest degree of circulatory inadequacy would naturally manifest itself at the extremity of the limb. The developments regularly observed both clinically and experimentally in acutely ischaemic limbs seem to be consistent with this conception

The extent to which the process is influenced by nervous vasomotor control has been the subject of much discussion As already mentioned in Chapter X (Section (l)), Mulvihill and Harvey (1931) found that the temporary decrease of surface temperature of the paw caused by ligation of the external iliac artery in dogs could be prevented by removal of the tributary sympathetic ganglia at the time of the ligation Stricker and Orban (1930) found that the massive gangrene of the hind limbs produced by resection of the aortic bifurcation in dogs could be prevented by prior lumbar sympathectomy. Experimental results of this type form the theoretical basis of the use of methods of suppression of sympathetic vasoconstrictor tone in the treatment of embolism. It may well be that such methods, if initiated sufficiently early, can accelerate the development of collateral circulation Whether they can actually increase the possible volume of collateral circulation or prevent gangrene in man is less certain The role of the sympathetic nervous system in the possible causation of injurious vasoconstrictor reflexes in human embolism has already been considered in Chapter X, and it was concluded that the evidence supporting this hypothesis is far from convincing.

The foregoing consideration of the mechanism of establishment of collateral circulation is necessarily brief and inadequate. It is intended mainly to lay emphasis on two aspects of the problem which have received little attention in clinical discussion of embolism firstly, the importance of anatomical factors and secondly, the role of ischaemic vascular relaxation. The importance of anatomical factors is further attested by a number of clinical observations made in the course of this study, and these are summarised in the next section.

Importance of anatomical structure

A number of observations emphasise the important role of anatomical

XII

Treatment

THE survey of outcome in Chapter VIII showed little difference in the limb survival rates of cases treated by embolectomy, cases treated medically and cases which received no treatment at all. The reasons for this were discussed and it was pointed out that it does not mean that no treatment is of any value However, in general, treatment of limb embolism is much less effective than has been supposed. Moreover, there are some forms of treatment which may be harmful and should therefore be avoided.

Many types of treatment have been supported by case reports claiming to show their advantages, only to be followed by others rejecting these claims. Most of the ' successes ' claimed are probably only examples of spontaneous recovery, which occurs in a considerable proportion of cases.

EMBOLECTOMY

On the whole, the results of embolectomy have hitherto been disappointing, and the relatively small number of true successes is shown by a comparison with the results of untreated embolism The disillusionment of some surgeons is understandable, but Grégoire's sad pronouncement ('. . cette opération décevante et illusoire ') was too pessimistic, for there have been many genuine successes, including not a few cases of aortic embolism. Statistical assessment of the value of the operation in a large series is no guide to its application in an individual case The fact that it is not more often successful is due to special difficulties, partly technical, partly due to the associated heart disease, and partly due to tardy diagnosis Some of these difficulties are not insuperable, and both surgeons and physicians can contribute to their solution Despite its limitations, embolectomy still holds first place in the treatment of embolism of the larger limb arteries. With the improvements in technique developed in recent years and with clearer definition of the indications for operation, its results should appear in a better light

Indications for operation

The majority of surgeons hold that embolectomy has little prospect of success if undertaken more than ten hours after the onset of symptoms. It is usually

7. Inferior mesenteric—superior haemorrhoidal—middle and inferior haemorrhoidal—internal iliac.
8. Superior mesenteric—inferior mesenteric—haemorrhoidal group—internal iliac.

Though numerous, these anastomoses are mostly small, yet they can carry a very considerable volume of blood. This was illustrated by one observation at operation on a case of right common iliac embolism. With a full exposure of the aortic bifurcation and both common iliac arteries, the abdominal aorta above its division and the right common iliac below the embolus were occluded by rubber tourniquets. When the right common iliac was opened, there was a very profuse non-pulsatile haemorrhage from the incision; this produced a sustained jet rising 2–3 cm above the artery The haemorrhage ceased at once when the left common iliac was compressed; it was evidently due to retrograde flow in that vessel from the collateral circulation of the lower aorta (Case No. 7).

In some cases the collateral circulation of the aorta will even suffice for survival of the whole of both lower limbs, though in most cases it proves inadequate for this The limb survival rate in occlusion of the bifurcation of the common iliac is much higher than that in aortic occlusion. This can hardly be due to any additional collateral circulation carried by branches of the common iliac itself, for these are few and minute. It is probably due to the fact that the collateral circulation is supplemented by cross-flow from the pelvic vessels of the opposite iliac system.

If the anatomical capacity of collateral arteries is usually so impressive, it might be expected that in embolism survival of the limb should be the rule rather than the exception Taking into consideration the large number of embolic occlusions which do not come under treatment at all (Chapter III), this supposition may not be very far from the truth. Certain it is that the risks of gangrene have been much exaggerated The anatomical study indicated, however, that there are arterial variations, especially in lower limbs, and these go far to explain the actual incidence of gangrene.

General physiological factors

Though the importance of anatomical structure has been emphasised, this is not to deny the influence of other factors The physiological factors of greatest importance, however, seem to relate more to the general circulation than to the arteries of the affected limb Any changes which alter the perfusion pressure available to the collateral arteries may decide the adequacy of the collateral circulation. In Chapter VI it was pointed out that in embolism of large arteries there may be a rise of general arterial blood-pressure. This is probably a favourable factor and should be borne in mind when treatment is considered. The influence of general circulatory function is strikingly illustrated by the phenomenon of 'relapsing ischaemic syndrome', described in Chapter VII (p.71).

XII

Treatment

THE survey of outcome in Chapter VIII showed little difference in the limb survival rates of cases treated by embolectomy, cases treated medically and cases which received no treatment at all. The reasons for this were discussed and it was pointed out that it does not mean that no treatment is of any value. However, in general, treatment of limb embolism is much less effective than has been supposed. Moreover, there are some forms of treatment which may be harmful and should therefore be avoided.

Many types of treatment have been supported by case reports claiming to show their advantages, only to be followed by others rejecting these claims. Most of the 'successes' claimed are probably only examples of spontaneous recovery, which occurs in a considerable proportion of cases.

EMBOLECTOMY

On the whole, the results of embolectomy have hitherto been disappointing, and the relatively small number of true successes is shown by a comparison with the results of untreated embolism. The disillusionment of some surgeons is understandable, but Grégoire's sad pronouncement (' cette opération décevante et illusoire ') was too pessimistic, for there have been many genuine successes, including not a few cases of aortic embolism. Statistical assessment of the value of the operation in a large series is no guide to its application in an individual case. The fact that it is not more often successful is due to special difficulties, partly technical, partly due to the associated heart disease, and partly due to tardy diagnosis. Some of these difficulties are not insuperable, and both surgeons and physicians can contribute to their solution. Despite its limitations, embolectomy still holds first place in the treatment of embolism of the larger limb arteries. With the improvements in technique developed in recent years and with clearer definition of the indications for operation, its results should appear in a better light.

Indications for operation

The majority of surgeons hold that embolectomy has little prospect of success if undertaken more than ten hours after the onset of symptoms. It is usually

supposed that failure in late operations is due to secondary thrombosis at the site of the arteriotomy. This may sometimes be so, but there are probably cases of grave ischaemia in which the fate of the limb has already been decided before operation is begun. The introduction in recent years of new techniques for clearing an embolised artery by retrograde flushing (Lerman, Miller and Lund (1930), Olwin, Dye and Julian (1953), Crawford and De Bakey (1956), Shaw (1956)) has encouraged the hope of success in some cases operated on more than ten hours after onset.

Many writers have suggested a preliminary period of medical treatment with observation for 2–3 hours, operation being undertaken if the ischaemia shows no improvement within this period. In Chapter VIII, reasons have been given for disagreeing with this suggestion A delay of 2–3 hours is not lightly to be accepted, especially if the effectiveness of medical treatment is so much in question. In cases seen very early, *i e.* less than two hours after onset, there may sometimes be rapid spontaneous improvement as the collateral circulation develops (*e.g.* Case No. 4), but this phase will not usually take longer than the time required to prepare for operation, and if it has not occurred within this time operation should not be delayed.

Assuming that the case is seen early enough, the indications for embolectomy can be very briefly stated:

1. All cases of embolism of the aortic bifurcation.
2. Cases of embolism of the iliac, femoral or axillary arteries in which signs of grave ischaemia are still present two hours or more after the onset of symptoms (Chapter VIII)

Embolectomy is not usually indicated for embolism of the brachial or popliteal arteries.

Technique

The writer is not qualified to discuss the operative technique of embolectomy, which has been described by many surgical experts (Key (1922), Danzis (1933), Pearse (1933), De Takats (1942), McClure and Harkins (1943), Veal and Dugan (1951), Olwin, Dye and Julian (1953), Pratt (1954), Dye, Olwin, Javid and Julian (1955), Crawford (1956)). Mention may be made of one case (No. 45) in which the practice of opening the artery below the embolus and attempting to extract it by suction through a catheter led to failure. The occluding clot was apparently only partially removed by this method and the restoration of blood-flow was incomplete and temporary. It seems wiser always to expose the artery fully at the upper limit of the occlusion and this emphasises the need for accurate localisation of the embolus. In combination with the method of retrograde flushing introduced by Olwin and his colleagues (1953), this type of

surgical approach should ensure complete removal of the embolus and its 'tail thrombus'.

Possible adverse effects of embolectomy

In one of the writer's cases (No. 7) it appears possible that the restoration by embolectomy of full blood-flow to muscles damaged by ischaemia may have aggravated the subsequent severe oedema, which was followed by permanent paralysis and fibrotic contracture. Griffiths (1938) described three cases of embolectomy followed by ischaemic contracture. In this study there were 75 cases who recovered without operation and only one of these developed contracture.

Theoretically, embolectomy carries the risk of provoking traumatic arterial spasm. Minor degrees of this may account for the not uncommon delay in return of distal pulses after operation, but there seems to be little risk of widespread spasm.

Other arterial operations

In Chapter XI, arterial massage was mentioned as a method of displacing an embolus distally and so reducing its ischaemic effects. This manoeuvre was originated by Deroyer (1880) and has been termed 'Melkung' (Schmorell (1933), Groth (1939)). Groth thought it had certain advantages over embolectomy. It is a fact that a more distally placed embolus offers less threat to the limb than a proximal one (Chapter VIII). If an embolus could be successfully manoeuvred into a side-trunk such as the internal iliac, restoration of the circulation in the limb might be achieved. There are advantages in avoiding arteriotomy, which causes injury to the arterial wall and usually results in narrowing of the lumen, thus facilitating secondary thrombosis. However, a 'blind' procedure of this kind does not recommend itself to most surgeons, except perhaps in a very ill patient.

Arteriectomy has been advocated, especially by the French surgeons, in cases seen too late for embolectomy (Haimovici (1937), Leriche (1947)). It has been held to reduce the risk of consecutive thrombosis and to remove the 'centre of irritation' postulated as a cause of reflex vasoconstriction. In view of the conclusions reached in Chapter V and Chapter X, arteriectomy would seem to have little place in the treatment of embolism.

MEDICAL TREATMENT

Anticoagulant drugs

The main theoretical basis for the use of anticoagulants in embolism is the presumption that consecutive thrombosis may be the cause of failure of collateral circulation. The relation of consecutive thrombosis to gangrene was found to be less close than had been expected (Chapter V).

Anticoagulants were used in 30 embolic incidents. Excluding brachial and popliteal embolism, there were 3 examples of axillary embolism and 16 examples of 'serious lower limb embolism'. Primary gangrene occurred in 8 of these 19 occlusions. There was a full post-mortem examination of the arteries in 7 of the 16 lower limb occlusions and consecutive thrombosis of 'major' degree was found only in one of them. However, this limb survived, whereas 5 of the other 6 developed primary gangrene The value of the anticoagulant therapy is therefore not apparent, but the material has no statistical value

Boyd (1948) has stated that anticoagulants may sometimes be harmful. He observed ecchymosis in the skin of a number of ischaemic limbs after treatment with dicoumarol and was of opinion that this had precipitated gangrene in some cases In Case No 46, dicoumarol poisoning appears to have accelerated death, but this was because of intraperitoneal haemorrhage. In the writer's practice, dicoumarol has for some years been replaced by phenindione, and no harmful effects have been seen which could be attributed to this drug.

This study provides no evidence of any weight on the value of anticoagulants in the treatment of limb embolism However, apart from any possible effect on the local result in the limb, there is a further important consideration. Embolism of a limb is very commonly followed very shortly afterwards by other embolic incidents This appears to be due to new intracardiac thrombosis, and with the aim of preventing this, oral anticoagulants have been given for a period of some weeks to all cases of limb embolism in which there was no contraindication Heparin was used concurrently for the first 48 hours, to produce immediate effect.

Suppression of sympathetic vasoconstrictor tone

On the presumption that sympathetic vasoconstrictor tone in collateral arteries might hinder their enlargement, procaine infiltration of the regional ganglia is often used in the treatment of embolism Milwidsky and his colleagues (1948 and 1952) have reported a number of examples of recovery from limb embolism after this treatment The writer's experience of it is limited, but no immediate improvement has ever been observed in an acutely ischaemic limb after such injections.

A centrally induced release of sympathetic vasoconstrictor tone throughout the body can be achieved by warming the torso with an electric cradle. This method will cause general vasodilatation and may therefore produce a fall of blood-pressure, which could impair collateral circulation in an ischaemic limb. For this reason the method appears undesirable. It certainly causes much discomfort to the patient.

Chemical vasodilators

The drug most widely employed as a vasodilator has been papaverine, first

used in embolism by Denk (1934). In recent years the benzyl-imidazoline compounds have been advocated.

Papaverine was given by intravenous injection in 18 embolic incidents In 15 of the cases no effect was observed and in one the drug was first used only after embolectomy. There were 2 cases in which there seemed to be an improvement in the colour of the limb shortly after the injection. One case (No. 7) was a very transient ischaemic syndrome which has been classified as pseudo-embolism. Case No. 9 was the only one in which the improvement was noted to recur with repeated injections. This was a septic embolism with possible arterial spasm; it has already been described in Chapter X (Section (j)).

Other vasodilators given to patients in this study were benzyl-imidazoline hydrochloride ('Priscol')—7 incidents, pancreatic extract ('Padutin')—7 incidents, and nicotinic acid or brandy in a few instances No favourable effect was observed with any of these preparations

The writer's experience of the various methods of producing vasodilatation is thus rather limited, but it gives very little evidence of their value in embolism. Furthermore, there is a theoretical reason against their use. In Chapter VI, attention was drawn to the reactive hypertension which often appears in embolism of the larger arteries and which may be favourable in its effect on collateral circulation. If *general* vasodilatation is produced by any method of treatment it is bound to cause some fall of general blood-pressure, and the harmful effects of this might outweigh any possible advantage The only vasodilator method free from this objection is local injection of the regional sympathetic ganglia, and if any such method is to be used this is the one of choice.

Vasodilators have also been administered by intra-arterial injection, *e.g* by Richards (1954) Richards was not impressed by the effects, and even when so given the drug must soon find its way into the general circulation and perhaps cause a fall of blood-pressure

Physical treatment

Two methods of physical treatment have been advocated for the encouragement of circulation in ischaemic limbs the 'Pavaex' suction-pressure chamber and intermittent venous occlusion (Landis and Gibbon (1933), Herrmann and Reid (1934), Wilson and Roome (1936)) Reports of their effects are conflicting, and natural recovery could explain all the figures quoted in their support Both methods entail some pressure on the skin of the limb, and this might be harmful

Care of the ischaemic limb

Muscular activity increases circulatory demand and an ischaemic limb is therefore usually kept at rest, but not restrained by bands or sandbags because of the risk of pressure on the skin, which may easily cause local necrosis. Eleva-

tion of the limb reduces the perfusion pressure in its arteries and is generally recognised as harmful. In Case No. 20, the limb was unwisely kept slightly elevated to aid venous return, because of old venous occlusions. Though the initial ischaemic signs in this limb were not of the gravest type, the circulation deteriorated and gangrene ensued. A lower limb is usually kept in a horizontal position, but there would seem to be some advantage in keeping it below heart level.

It has been shown experimentally that a passive rise in the temperature of an ischaemic limb can precipitate gangrene, presumably by increasing its metabolic demands beyond the capacity of the depleted circulation, or perhaps by accelerating the formation of toxic metabolites. An embolised limb is therefore usually kept cool (Allen (1938), Brooks and Duncan (1940), Freeman (1940)). On the other hand, chilling tends to cause contraction of arteries. Case No. 24 was the only one treated by active cooling of an ischaemic lower limb. This patient had surgical excision of a syphilitic popliteal aneurysm. In the immediate post-operative period a trial was made of active cooling of the limb by means of an electric fan The ischaemic signs remained severe during this treatment and immediately improved when it was discontinued. The most satisfactory compromise is to expose the limb without coverings in a draught-free room at ordinary temperature (15–18° C.), and this was the usual routine.

General treatment

Pain should be relieved by suitable drugs, this will help to ensure relaxation and rest for the ischaemic limb. As long as the limb appears to be surviving, strong narcotics are to be avoided, for they may cause a fall of blood-pressure

If collateral circulation depends so largely upon anatomical factors, the most important element of clinical management is suitable treatment of the heart disease to maintain the best possible general circulation Overdosage of digitalis must be avoided, and diuretics used with discretion so as to run no risk of haemoconcentration. The question of active measures to increase blood-pressure is a difficult one, for a rise of blood-pressure may further embarrass a labouring heart and so do more harm than good. At all events, every effort should be made to avoid a *fall* of blood-pressure, and for this reason vasodilator drugs and electric cradles are probably not good practice.

Amputation

Once gangrene is evident (and it is usually heralded by extensive extravasation staining), there is nothing to be gained by delaying amputation. On the contrary, the rapid general deterioration which often sets in with the onset of gangrene may sometimes be arrested by prompt amputation. This is important if there is another embolised limb whose collateral circulation might be endangered by a serious decline in the general condition of the patient.

PREVENTION OF EMBOLISM

Treatment of limb embolism is on the whole disappointing and the problem of prevention is therefore very important. Limb embolism itself accounts only for a relatively small number of deaths in patients with heart disease, but internal systemic embolism is a very common cause of death or grave incapacity, and any success in the prevention of embolism in general would avert many deaths and save much invalidism.

The primary cause of systemic embolism is intracardiac thrombosis, and it is to the prevention of this that attention must be turned. There is reason to regard over-dosage of digitalis as a contributory factor in some cases (Chapter IV) A full understanding of the potency of digitalis preparations (particularly digoxin) and increased vigilance in supervision may prevent a certain number of embolic disasters. If signs of over-dosage are noted, the prophylactic use of anticoagulants until these signs have passed off may help to avert embolism.

Any patient who has had one embolism is liable to suffer others, and there is a case for the prophylactic use of anticoagulants in such cases, at least for a few weeks.

Operations on the heart

Dock (1946) was impressed by the fact that in patients who have had systemic embolism adherent thrombi are very often found in the left auricular appendage and he suggested that resection of this part of the auricle might be an effective prophylactic measure against embolism. It seems probable that thrombi are found in this site because it is here that adhesion most readily occurs, and that the thrombi which cause embolism are those which form in the atrium and never become adherent at all However, Dock's suggestion has been acted upon by some surgeons, for example Madden (1949), who reported two cases of this operation The results were not encouraging, for one patient developed hemiplegia during the course of the operation and the other died suddenly, probably of embolism, nine days later (the description of the symptoms suggests that the latter patient had excessive dosage of digitalis).

Jordan, Schiefley and Edwards (1951) examined the records of 11,536 autopsies at the Mayo Clinic and found 51 cases of mitral stenosis with adherent intracardiac thrombi 50% of those found on the left side of the heart were situated in the auricular appendage and 50% elsewhere Systemic emboli were equally common in either case They concluded that '. . . resection of the left auricular appendage offers only a 50% chance of eliminating the source for systemic arterial emboli '. The logic of this is not apparent, for there are no grounds for supposing that thrombi cannot form in the atrium after removal of the appendage and as they themselves pointed out, mural thrombi elsewhere on the left side of the heart are associated with systemic embolism just as commonly

as appendicular thrombi. The prospect of eliminating the source for emboli by this operation must be very much less than '50%', if indeed it exists at all.

The incidence of old arterial occlusions in patients with mitral stenosis (Chapter III) and the incidence of auricular fibrillation in embolism (Chapter IV) both show very clearly that the most important factor in the causation of *intracardiac thrombosis, and therefore of embolism, is auricular fibrillation.* Mitral stenosis itself carries but little risk of embolism so long as the heart rhythm remains regular. If the onset of fibrillation could be averted or long delayed, many cases of embolism would be prevented.

At present, interest centres upon mitral valvotomy as the treatment most likely to avert or delay the onset of auricular fibrillation. Hitherto, the decision to operate has usually been based on evidence of cardiac insufficiency which itself may appear only after the onset of auricular fibrillation. If the risk of embolism be taken into consideration as well, and if the operation fulfils the hope that it will avert fibrillation, then it would seem that earlier operation has much to be said for it. Valvotomy before the onset of auricular fibrillation might also tend to reduce the risk of embolism as an operative complication.

XIII

Summary of Main Conclusions

1. Spontaneous recovery in untreated limb embolism

Examination of the limb pulses and enquiry into the history of patients with mitral stenosis show that many of them have had limb embolism with natural recovery. In the patients with auricular fibrillation the proportion showing this is more than one quarter and it increases with increasing age. (CHAPTER III)

2. Aetiology of limb embolism

(*a*) Limb embolism is very rare in patients without heart disease. (CHAPTER IV)

(*b*) Auricular fibrillation is the most important aetiological factor. (CHAPTER IV)

(*c*) Over-dosage of digitalis is a contributory factor in some cases. (CHAPTER IV)

3. Incidence of embolism at different anatomical sites

(*a*) Embolism is commonest in the smallest arteries and least common in the largest. (CHAPTER V)

(*b*) This natural anatomical incidence is not evident in hospital series because many of the less serious cases do not come under observation. (CHAPTER V)

4. Character of embolic thrombi

Embolism is usually caused, not by detachment or fragmentation of old mural thrombi but by newly formed intracardiac thrombi which have never become adherent (CHAPTER V)

5. Consecutive thrombosis

There is little evidence that consecutive thrombosis is commonly responsible for precipitating gangrene in an embolised limb. Its extent is determined by anatomical factors, and it is probably more often a result of inadequacy of collateral circulation than a cause of it. (CHAPTER V)

as appendicular thrombi. The prospect of eliminating the source for emboli by this operation must be very much less than ' 50% ', if indeed it exists at all.

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14. Diagnosis of the site of an embolus

In localisation of the site of an embolus:

(a) The sites of the pulse deficiencies take precedence over all other signs.
(b) A *weakened* arterial pulse has the same significance as an *absent* pulse.
(CHAPTER VII)

15. 'Relapsing ischaemic syndrome'

In some cases of old limb embolism who have recovered spontaneously, subsequent heart failure may precipitate failure of the collateral circulation, producing an acute ischaemic syndrome which may closely resemble a very recent embolic occlusion. (CHAPTER VII)

16. Limb survival rates in embolism at different sites

(a) In limb embolism the limb survival rate is inversely proportional to the size of the artery occluded. (CHAPTER VIII)
(b) Spontaneous recovery may occur in embolism at any site, though it is not common in aortic embolism. (CHAPTER VIII)
(c) In brachial and popliteal embolism, survival of the limb is almost invariable. (CHAPTER VIII)

17. Effect of treatment on outcome of limb embolism

The limb survival rates of embolic occlusions treated either surgically or medically are no higher than that of untreated embolism. (CHAPTER VIII)

18. Reappearance of suppressed pulses after embolism

Early reappearance of the suppressed pulses is not uncommon after embolism, especially in upper limbs (CHAPTER VIII)

19. Prognosis in limb embolism—aortic embolism excluded

Provided two hours have elapsed from the onset of the symptoms, the probable fate of the limb can be decided on the basis of the ischaemic signs, without temporising (CHAPTER VIII)

20. Impossibility of prognosis in aortic embolism

In aortic embolism the fate of the limb cannot be predicted, for sudden regression often occurs after initial improvement. (CHAPTER VIII)

21. Anatomical variations in collateral arteries

Post-mortem arteriography shows that there are considerable variations in the extent of anatomical development of arterial collaterals in different persons and at different sites These variations go far to explain the incidence of gangrene in embolism of the limbs. (CHAPTER IX)

6. Pain in embolism of the limbs

Pain localised near the site of impaction of an embolus is uncommon in *comparison with the pain situated in the more distal area of the ischaemic signs.* (CHAPTER VI)

7. Reactive hypertension in embolism of large arteries

A rise of general arterial blood-pressure is not uncommon during the early period after embolism of the aorta or the iliac arteries. This is probably a favourable factor. (CHAPTER VI)

8. Assessment of the gravity of ischaemia

The signs most useful for clinical assessment of the gravity of ischaemia are:

(*a*) *The extent of pallor*
(*b*) The extent of sensory impairment.
(*c*) Deficiency of venous filling. (CHAPTER VI)

9. Duration of ischaemic signs in recovering limbs

In limbs with adequate collateral circulation, signs of grave ischaemia do not persist for more than two hours after onset (CHAPTER VI)

10. Persistence of pulses distal to an embolus

Arterial pulsation, though usually weakened, is not uncommonly felt beyond the site of an embolic occlusion in a large limb artery. (CHAPTER VI)

11. Ischaemic muscle damage in limb embolism

Ischaemic muscle damage is not uncommon in limb embolism, but in limbs which recover naturally it rarely results in contracture. There is some indication that contracture may be more common after successful embolectomy (CHAPTER VI)

12. Diagnosis of limb embolism

The presence of heart disease of appropriate type is the most important factor in deciding whether an arterial occlusion is embolic. (CHAPTER VII)

13. 'Pseudo-embolism'

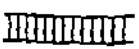
(*a*) There are occasional instances of acute ischaemic syndrome in patients with heart disease, due not to embolic occlusion but apparently to arterial spasm of obscure origin. (CHAPTER VII)
(*b*) The transient character of the symptoms does not distinguish pseudo-embolism, for in some cases of proved embolic occlusion the symptoms may be equally transient. (CHAPTER VII)

Appendix I

Diagrams illustrating arterial occlusions

The extent and character of the arterial occlusions found at autopsy in 12 representative cases of lower limb embolism are illustrated by diagrams in Figs 26 to 37.

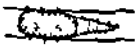
In these diagrams, recent black thrombus is represented by hatching, red thrombus by cross-hatching and organised thrombus by stippling. Firm thrombus is represented by close-set hatching, soft thrombus by widely spaced hatching. An outline surrounding the hatching indicates a well defined thrombus. Adhesion is represented by ' bristle ' marks along the margin, close-set for dense adhesion and widely spaced for light adhesion. Examples of these symbols are shown below:



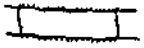
Soft black thrombus, non-adherent, occluding the artery completely.



Well defined soft red thrombus, non-adherent, occluding the artery completely.



Well defined firm red thrombus, lightly adherent, occluding the artery completely, with firm black tapering ' tail thrombus ', lightly adherent, not fully occluding the artery.



Organised thrombus, densely adherent

22. Arterial spasm in limb embolism

Critical examination of the evidence indicates that the importance of embolic arteriospasm has been much exaggerated. (CHAPTER X)

23. The genesis of ischaemia in limb embolism

(*a*) The most important factor in deciding the degree of ischaemia in an embolic occlusion is the anatomical structure of the system of arterial collaterals. (CHAPTER XI)

(*b*) The most important physiological factors are the efficiency of the general circulation and the level of the arterial blood-pressure. (CHAPTER XI)

24. Treatment of limb embolism

Though the number of successes is not great, embolectomy holds first place in the treatment of embolism of the larger limb arteries. Little benefit can be shown from the various forms of medical treatment in use and some of them may be harmful (CHAPTER XII)

Appendix I

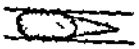
Diagrams illustrating arterial occlusions

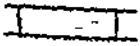
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Soft black thrombus, non-adherent, occluding the artery completely.


Well defined soft red thrombus, non-adherent, occluding the artery completely


Well defined firm red thrombus, lightly adherent, occluding the artery completely, with firm black tapering ' tail thrombus ', lightly adherent, not fully occluding the artery.


Organised thrombus, densely adherent.

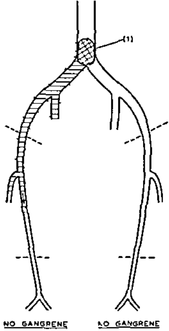


Fig. 26 (*Case No 4*) Embolism of aortic bifurcation Estimated age of occlusion (1) 10 days

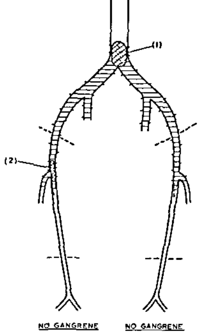


Fig 27 (*Case No 14*) Embolism of aortic bifurcation and R common femoral artery. Estimated age of occlusions (1) 9 days, (2) 9 days

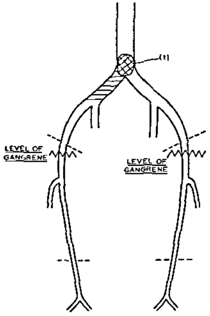


Fig. 28 (*Case No 25*) Embolism of aortic bifurcation Estimated age of occlusion (1) 35 hours.

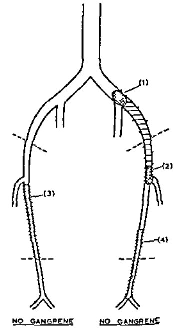


Fig 29 (*Case No 29*) Embolism of L common iliac, L common femoral and L. and R superficial femoral arteries Estimated ages of occlusions (1) 46 days, (2) 46 days; (3) 1 year, (4) 1 year.

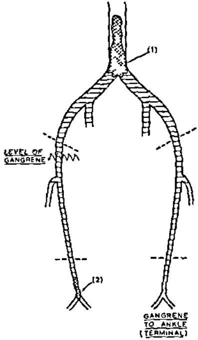


FIG. 30 (*Case No.* 30) Embolism of aortic bifurcation and R. popliteal artery. Estimated ages of occlusions. (1) 1–4 months, (2) 1–4 months.

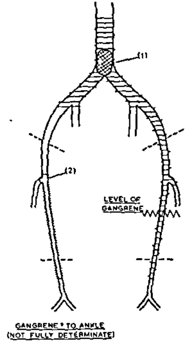


FIG 31 (*Case No* 31) Embolism of aortic bifurcation and R common femoral artery. Estimated ages of occlusions. (1) 6 days, (2) Unknown

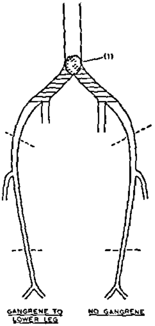


FIG. 32 (*Case No* 47) Embolism of aortic bifurcation Estimated age of occlusion (1) 6 days

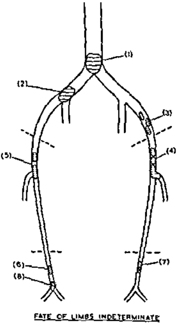


FIG. 33 (*Case No.* 64) Multiple embolisms in the lower limbs Estimated ages of occlusions. (1) to (7) A few hours, (8) Unknown

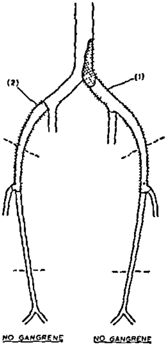


FIG. 34 (*Case No 69*). Embolism of L common iliac and R external iliac arteries Estimated ages of occlusions (1) 1 year, (2) 1 year

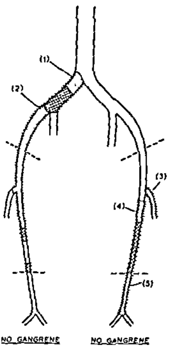


FIG. 35 (*Case No 75*) Multiple embolisms of both lower limbs Estimated ages of occlusions All unknown

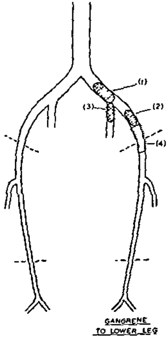


FIG 36 (*Case No. 76*) Embolism of L. common iliac, internal iliac and external iliac arteries. Estimated ages of occlusions (1), (2), (3) 2 months; (4) Unknown

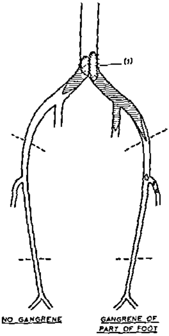


FIG. 37 (*Case No. 81*) Embolism of aortic bifurcation. Estimated age of occlusion (1) 4 weeks.

Appendix II

CLINICAL CASE MATERIAL

In Appendix II, the general nature of each case of the clinical series is indicated by a brief epitome of the record. In addition to 69 cases of arterial embolism, with a total of 122 separate incidents of limb embolism, 12 cases of non-embolic arterial occlusion are included, as they illustrate certain problems of diagnosis and prognosis.

The cases are numbered consecutively in the approximate chronological order of their admission to hospital. The 12 cases of non-embolic arterial occlusion are Nos. 18, 19, 24, 26, 32, 33, 35, 40, 41, 43, 57, 71.

CASE No. 1. F.A.C 58 years. (F) *Admitted to M E H, 15 7 38*

A woman of 58 years, suffering from mitral stenosis with auricular fibrillation but in good condition and without heart failure, who had embolism of the bifurcation of the aorta. Though the onset of symptoms was not very sudden, severe 'shock' developed within 5 hours At this time the blood-pressure was high (190/130), though subsequent autopsy showed no evidence of essential hypertension (The history suggests that she had a prior embolism in the left lower limb a few weeks earlier, with spontaneous recovery)

Gangrene of both lower limbs ensued and the patient died five days after the onset of symptoms *Autopsy*

CASE No 2. E P 65 years. (F) *Admitted to M E H, 3 2 39*

A woman of 65 years, suffering from mitral stenosis with auricular fibrillation and congestive heart failure. She developed right brachial embolism, accompanied by syncopal symptoms, and died within twelve hours The patient did not survive long enough for the fate of the limb to be assessed, but up to a few hours before death, despite general circulatory collapse, the ischaemic signs were not severe *Autopsy*

CASE No 3 A.W 40 years. (F) *Admitted to M E H, 24 6 39*

A woman of 40 years, suffering from mitral stenosis with auricular fibrillation and treated for congestive failure by rapid digitalisation Two days after the beginning of treatment she had embolism of the bifurcation of the aorta. The onset of symptoms was gradual and they were mild, with hardly any pain A very weak pulse returned in the right femoral artery one month after the embolism. The ischaemic signs were only moderate and rapidly improved and both limbs survived with minimal dermal necrosis at the resting-points of the heels This healed and she recovered fairly good function in both limbs, though liable to coldness and cramps in the legs in cold weather.

Four years after the embolism, weak pulses had returned at both groins but not elsewhere in either limb

CASE No 4 W.E.C.T. *22 years.* (M) *Admitted to M E.H., 24.10.41*

A man of 22 years, suffering from acute pneumococcal endocarditis, who had embolism of the bifurcation of the aorta He survived ten days before dying of the endocarditis, and though function was impaired in the lower limbs, especially the right, *no gangrene ensued* (*Fig. 26*) *Autopsy.*

CASE No 5. W H. 88 years (M) *Admitted to P.H., 7 8 43*

A man of 88 years, suffering from hypertensive heart disease with auricular fibrillation, who had acute ischaemic syndrome in the left lower limb. This resulted in gangrene to mid-thigh, with death four days after onset. The only recent thrombus was found in the left external iliac artery, filling the segment enclosed between two much older and firmly adherent thrombi occluding the common iliac and common femoral. There was also an occlusion of long standing in the right brachial artery, but no ischaemic signs were *present in this limb.*

This was probably a case of ' relapsing ischaemic syndrome ', due to failure of a previously adequate collateral circulation and precipitated by general circulatory failure. *Autopsy*

CASE No 6 B M 41 years (F) *Admitted to P H , 19 12.43*

A woman of 41 years, suffering from mitral stenosis with auricular fibrillation, who had embolism of both kidneys with very severe reflex vomiting, proceeding to acute dilatation of the stomach. A few days later she had embolism of the bifurcation of the aorta During the first 24 hours the femoral pulses remained palpable, though weakened, and the case was wrongly diagnosed as bilateral femoral embolism. Collateral circulation appeared adequate for three days but then suddenly failed and bilateral gangrene ensued, the patient dying of this 11 days later *Autopsy.*

CASE No. 7 L R J 44 years (F) *Admitted to P H , 26.7.44*

A woman, suffering from mitral stenosis with auricular fibrillation, who from the age of 44 years had a number of embolic incidents. The first occurred in the right lower limb, with rapid spontaneous recovery Three weeks later she had embolism of the right common iliac artery (*the embolus appears to have halted for a time at the bifurcation of the aorta*) Embolectomy was performed 3½ hours after onset, with restoration *of the femoral pulse, but though no gangrene ensued there was very severe ischaemic* damage to the leg muscles, resulting in fibrotic contracture and permanent paralytic foot-drop The right femoral pulse gradually disappeared three weeks after operation and never returned

During the next two years there were two cerebral and two visceral embolic syndromes and three separate attacks of ischaemic symptoms in the left lower limb. There was transient loss of the left femoral pulse in the first two attacks and permanent disappearance some *time after the second.*

CASE No. 8. J S. 65 *years* (F) *Admitted to P.H., 26 1.45*

A woman of 65 years, suffering from mitral stenosis with auricular fibrillation, operated upon for bilateral common iliac embolism 6½ hours after the onset of ischaemic symptoms. Bilateral embolectomy was performed and strong and *lasting pulsation* was

restored in both femoral arteries. No pulsation returned in the popliteal and foot arteries and gangrene of both legs ensued, necessitating bilateral amputation. There was a history of transient ischaemic symptoms in the left leg three years previously and after amputation an old-standing embolus was found at the lower end of the left popliteal artery.

In addition to the bilateral common iliac embolism, there must also have been occlusion of both common femoral arteries The failure of return of the popliteal pulses after restoration of the femoral pulses should have enabled this to be recognised at operation

CASE No. 9. F.R.H. 55 years. (M) *Admitted to P H, 7.5.45*

A man of 55 years, suffering from mitral stenosis with subacute bacterial endocarditis, who had embolism of the right common femoral artery with ischaemic symptoms of only moderate severity. By the third day, the collateral circulation appeared quite adequate and remained so until the ninth day, but as the patient's general condition deteriorated it failed and gangrene of the foot ensued, three days before death. *Autopsy*

CASE No. 10 E A A. 58 years. (F) *Admitted to P H, 11.5 45*

A woman of 58 years, suffering from mitral stenosis with auricular fibrillation, who had (at uncertain intervals) successive embolic occlusions in the right superficial femoral, right deep femoral and left common femoral arteries. In each case the limb recovered quickly without gangrene

Three weeks after the left common femoral embolism, she died suddenly from impaction of a large auricular thrombus in the stenosed mitral valvular orifice *Autopsy.*

CASE No 11. F S. 33 years (F) *Admitted to P.H, 11 5 45*

A woman of 33 years, suffering from mitral stenosis with auricular fibrillation, admitted to hospital for congestive failure and treated by rapid digitalisation. She developed symptoms of over-dosage and four days later had embolism of the right axillary artery A weak pulse could be felt in the brachial and radial arteries for several days, but these pulses finally disappeared and did not return up to the time of discharge from hospital, six weeks later The ischaemic symptoms were very slight and lasted only one day.

CASE No 12 A McB 50 years (M) *Admitted to P H, 7 8 45*

A man of 50 years, suffering from thyrotoxicosis with auricular fibrillation and congestive heart failure, treated by rapid digitalisation. After two doses of digoxin he had embolism of the right brachial artery The ischaemic signs were not severe and cleared up completely in two weeks A weak radial pulse returned six weeks after the embolism and the circulation in the limb remained adequate until the patient's death from heart failure, more than three months later. *Autopsy*

CASE No. 13 D E J 53 years. (F) *Admitted to P.H, 19.11.45*

A woman of 53 years, suffering from mitral stenosis with auricular fibrillation, admitted to hospital for embolism of the right common femoral artery. Five years earlier she had had cerebral embolism and, probably at the same time, embolism of the

left external iliac artery No gangrene had ensued and the ischaemic symptoms probably escaped attention owing to the co-existing left hemiplegia.

The ischaemic symptoms in the right leg were only of moderate severity and the limb survived for nearly two weeks after onset A further cerebral embolism followed and the patient died 19 days after admission to hospital Extravasation staining appeared in the right leg and foot shortly before death *Autopsy.*

CASE No 14 J E 50 years (F) *Admitted to P H , 27.11.45*

A woman of 50 years, suffering from mitral stenosis with auricular fibrillation, who had embolism (probably almost simultaneous) of the bifurcation of the aorta and the right common femoral artery, followed by successive embolism of both internal carotid arteries.

During the first few days, both femoral pulses and the left popliteal pulse remained palpable and this led to an erroneous diagnosis of simultaneous embolism of the right common femoral and left popliteal arteries The femoral pulses subsequently disappeared but the ischaemic signs were only of moderate severity and improved rapidly. Up to the ninth day after onset, when the patient died of the second cerebral embolism, the circulation in both legs remained good (Fig. 27) *Autopsy*

CASE No 15 G P 43 years (F) *Admitted to P H., 4 12 45*

A woman of 43 years, suffering from mitral stenosis and aortic incompetence with auricular fibrillation and over-dosage of digitalis, who had acute ischaemic symptoms in the left lower limb There were incomplete and variable pulse deficiencies in both lower limbs The ischaemic symptoms were slight and cleared up in a few days, femoral pulsation, though reduced in volume on both sides, was present for at least 17 days after the onset of the ischaemia

Eighteen months later, both femoral pulses were found to be absent It seems probable from the history that there was more than one embolic incident, but the sites of the embolisms were not clearly established

CASE No. 16. V I 58 years (F) *Admitted to P H , 29 12.45*

A woman of 58 years who had anterior myocardial infarction with intraventricular thrombosis Nine days later she had an acute ischaemic syndrome in the right arm, with suppression of the brachial and radial pulses The ischaemic symptoms were not severe and cleared up completely in three weeks, with return of the brachial and radial pulses

Nearly five months later the patient died of the heart disease and at autopsy no evidence of arterial occlusion could be found in the right upper limb. This is an example of ' pseudo-embolism '. *Autopsy.*

CASE No. 17. S.M. 32 years (M) *Admitted to P.H., 5 3.46*

A man of 32 years, suffering from old rheumatic aortic and mitral valvular disease with subacute bacterial endocarditis. He had embolism of the right popliteal artery and this caused little or no disturbance of the circulation of the limb. *Autopsy.*

CASE No. 18. J W. 76 years. (M) *Admitted to P.H , 30 5 46*

A man of 76 years, suffering from arteriosclerotic cerebral vascular degeneration,

who died of broncho-pneumonia. A few days before death, pulsation disappeared in the brachial and radial arteries, first on the left side and then on the right, but the ischaemic signs were very slight and transient.

At autopsy, the arterial occlusions were found to be due to a subacute arteritis of rare type, affecting the axillary and brachial arteries on both sides, with recent thrombotic closure of the right brachial. *Autopsy.*

CASE No. 19. S.S 85 years. (F) *Admitted to P.H., 9.9.46*

A woman of 85 years, suffering from extreme atherosclerosis, with aneurysmal dilatations of the abdominal aorta and the left superficial femoral artery. The femoral aneurysm became occluded by thrombosis with resulting gangrene of the foot. The patient died of broncho-pneumonia a few days later. *Autopsy*

CASE No. 20. A.M.R. 75 years. (F) *Admitted to W.H , 3.9 46*

A woman of 75 years, suffering from auricular fibrillation, who was treated by rapid digitalisation and developed signs of over-dosage. The heart reverted to sinus rhythm and five or six days later there was an embolic occlusion of the left brachial artery. Embolectomy was performed at 2½ hours, but there was no restoration of pulsation in the radial artery The ischaemic symptoms were of moderate severity and cleared up in a few weeks.

Auricular fibrillation recurred and four months after the brachial embolism there was simultaneous embolism of the right femoral and left popliteal arteries Gangrene ensued in the right leg and the limb was amputated (It had been treated in a slightly elevated position, which may have been harmful.) The left leg survived but showed minor chronic ischaemic symptoms for some months

Pulsation returned in the left brachial and radial arteries about 2½ years after the occlusion

CASE No 21 S S 53 years (M) *Admitted to W H , 18 11.46*

A man of 53 years who had a prolonged attack of auricular paroxysmal tachycardia. After several days in the attack, he had embolism of the right common iliac artery and was admitted to hospital three days later The history suggests that the embolus had first occluded the aortic bifurcation and had then migrated into the right common iliac

Treatment with papaverine had no effect and severe pain persisted in the foot, with signs of ischaemic damage in the muscles of the leg. The viability of the limb was in doubt for nearly three weeks, but the skin of the foot then became gangrenous and the limb was amputated below the knee

CASE No 22 A S 57 years (F) *Admitted to W H , 28 3.47*

A woman of 57 years, suffering from mitral stenosis with auricular fibrillation and pneumonia, who had embolism of the bifurcation of the aorta She was admitted to hospital about 30 hours later and pulsation was then felt in the femoral and popliteal arteries on the right side but not on the left. An erroneous diagnosis of simultaneous left common iliac and right popliteal embolism was made.

Gangrene of both lower limbs ensued and the patient died of this 25 days after the

onset of the ischaemic symptoms. The right femoral pulse remained palpable up to three days before death. *Autopsy.*

CASE No 23. B D 70 years (F) *Admitted to W H., 12.4 47*

A woman of 70 years, suffering from hypertensive heart disease with auricular fibrillation and bronchitis. While in hospital she had an occlusion of the right femoral artery (possibly embolic, possibly thrombotic) She complained of pain in the limb, but the ischaemic symptoms were not severe, attracted little attention, and cleared up in a few days

Nearly four weeks later she had occlusion of a branch of the superior mesenteric artery. Two days later, apparently as a result of the collapse and fall of blood-pressure caused by peritonitis, the collateral circulation in the right leg, previously adequate, failed and an acute ischaemic syndrome developed quite suddenly in this limb

This is an example of ' relapsing ischaemic syndrome ', simulating a more recent arterial occlusion *Autopsy.*

CASE No 24. W S. 42 years (M) *Admitted to W.H , 18.4.47*

A man of 42 years who had excision of a specific aneurysm of the right popliteal artery, preceded by lumbar ganglionectomy The ischaemic signs after operation were only moderately severe They became worse when the limb was cooled for some hours by an electric fan and improved at once when this was discontinued

The limb recovered well and subsequent arteriography showed a free collateral circulation

CASE No 25 W P 62 years (M) *Admitted to W H , 30 4 47*

A man of 62 years, suffering from mitral stenosis with auricular fibrillation, who had three cerebral embolisms over a period of seven years Shortly after the last of these, he had embolism of the bifurcation of the aorta There were severe collapse symptoms and both lower limbs rapidly became gangrenous to the groins The patient died 35 hours after the first symptoms of the aortic embolism (Fig 28) *Autopsy.*

CASE No 26 C P G 40 years (M) *Admitted to W H., 2.4.47*

A man of 40 years, previously quite well, who had a fracture of the sacrum in close proximity to the left common iliac vessels A few days later he began to have repeated slight pulmonary embolisms During the following 2½ years he had recurrent attacks of vascular thrombosis, both venous and arterial, involving the superficial veins of both legs (' thrombo-phlebitis migrans '), the deep veins of the left leg and the main arterial trunks of both lower limbs, first occlusion of the left superficial femoral artery (7½ months *after the accident) and later occlusion of the right external iliac artery (12 months* after the accident). The initial ischaemic symptoms in both lower limbs were slight and rapidly improved, but intermittent claudication developed and persisted in both legs

Excluding the remote possibility of ' paradoxical embolism ', this appears to be a case of ' phlebo-arteritis ', in its clinical course closely resembling Buerger's disease but difficult to dissociate from the injury.

CASE No. 27. G W. 75 years (M) *Admitted to W.H , 19 9.47*

A man of 75 years, suffering from coronary atherosclerosis with auricular fibrillation

and congestive heart failure, who had embolism of the right common femoral artery and probably of the left upper popliteal artery, followed at an uncertain interval by embolism of the aortic bifurcation.

He lived for three weeks after the first symptoms of limb embolism and despite increasing heart failure no gangrene ensued. *Autopsy*.

CASE NO. 28. D.T 30 years. (F) *Admitted to W.H , 9 8.47*

A woman of 30 years, suffering from mitral stenosis and subacute bacterial endocarditis, who had bilateral popliteal embolism without any treatment. No acute onset was remembered, ischaemic symptoms were very slight and recovery was complete

She died six months later of cardiac failure, the circulation in both legs remaining good to the end. *Autopsy*.

CASE NO. 29 M.F. 59 years. (F) *Admitted to W H., 20.9.47*

A woman of 58 years, suffering from mitral stenosis with auricular fibrillation, survived bilateral embolism of the superficial femoral arteries, untreated, with perfect functional recovery in both limbs One year later she had symptoms suggesting abdominal visceral embolism and was admitted to hospital Treatment with digitalis was instituted and symptoms of over-dosage appeared A few days later she had embolism of the left retinal artery, followed two days later by two embolic occlusions of the main arterial trunk of the left lower limb, one in the common iliac and one in the common femoral. The ischaemic symptoms were not severe and cleared up completely in 2-3 weeks. (Fig. 29.)

Forty-two days after the iliac embolism she had a cerebral embolism, which caused death four days later. *Autopsy*

CASE NO 30. J M. 73 years (F) *Admitted to W H , 8 10 47*

A woman of 73 years, suffering from myocardial fibrosis with auricular fibrillation and congestive heart failure After initial improvement the failure recurred, affecting particularly the left ventricle (pulmonary oedema and mental confusion) The patient then developed acute ischaemic syndrome of both lower limbs, with extensive gangrene of the right one, and died four days after onset of the ischaemic symptoms The left lower limb appeared to be surviving up to the day of death, when signs of incipient gangrene appeared in the foot

Autopsy showed embolic occlusion of the aortic bifurcation and the right popliteal artery. Both these occlusions were obviously of at least some weeks' standing, but there was extensive consecutive thrombosis of more recent date (Fig 10 and Fig. 30)

This is an example of ' relapsing ischaemic syndrome ', due to failure of a previously adequate collateral circulation and probably precipitated by heart failure. *Autopsy*.

CASE NO 31 A M O 74 years. (F) *Admitted to W H., 29.10 47*

A woman of 74 years, suffering from hypertensive heart disease, myocardial infarction and auricular fibrillation Seventeen days after the myocardial infarction she had embolism of the bifurcation of the aorta She was admitted to hospital four days later and then had bilateral gangrene, much more extensive on the left side than on the right. She died on the sixth day after the embolism.

Autopsy revealed that she had an old-standing occlusion of the right femoral artery, possibly embolic. The gangrene resulting from the aortic embolism was much less extensive on the side with the older occlusion of the femoral artery (Fig. 31.) *Autopsy.*

CASE No 32. J J 48 years. (M) *Admitted to W H , 13.12.47*

A man of 42 years, suffering from hypertension, in 1942 developed chronic indolent ulceration of the left leg, for which the limb was amputated in August, 1947 Soon after this he began to suffer ischaemic symptoms in the right leg, culminating in localised gangrene of the foot Both femoral pulses were then found to be absent (earlier records of the limb pulses are incomplete, but pulses were recorded as present in both feet in 1946). The right lower limb was amputated through the thigh in January, 1948 A few months later all pulses disappeared in the left upper limb, without any ischaemic symptoms

This may have been a case of Buerger's disease Histological examination of the arteries of the amputated right lower limb lent some support to this view.

CASE No 33 W C 62 years (M) *Admitted to W H , 20 12 47*

A man of 62 years, suffering from arteriosclerotic disease of both lower limbs with right popliteal aneurysm The left superficial femoral artery became occluded by thrombosis, producing an acute ischaemic syndrome He was admitted to hospital four days after onset of the ischaemic symptoms The ischaemia was severe and there was permanent paralysis and fibrosis of most of the muscles below the knee, but the only necrosis was limited to the tips of two toes and this healed

Fifteen months later, the right-sided popliteal aneurysm became occluded by thrombosis and the ischaemic symptoms on this occasion were slight and transient The limb recovered in three weeks and the patient returned to his work

CASE No 34 E C 65 years (F) *Admitted to W H , 24 1 48*

A woman of 65 years, suffering from hypertensive heart disease with auricular fibrillation and congestive heart failure After four days' treatment with digitalis and diuretics she had acute ischaemic syndrome in both lower limbs, probably due to embolism of the right femoral and left iliac arteries The right lower limb recovered rapidly, but the left foot became gangrenous and there was severe ischaemic damage to the muscles of the surviving part of the limb *Autopsy*

CASE No 35 T.C. 70 years (M) *Admitted to W H , 16.4 48*

A man of 70 years, suffering from old myocardial infarction and congestive heart failure, who developed auricular fibrillation A few days after onset of the arrhythmia he had acute ischaemic syndrome in both lower limbs with bilateral gangrene, from which he died in four weeks. Autopsy showed arterial occlusions of arteriosclerotic type, which had obviously been present far longer than the duration of the acute ischaemic symptoms

This was probably an example of ' delayed ischaemic syndrome ', resulting from failure of a previously adequate collateral circulation and precipitated by the sudden deterioration of the heart condition *Autopsy.*

Case No. 36. M.A.H. 50 years. (F) *Admitted to W.H., 27.4.48*

A woman of 50 years, suffering from mitral stenosis with auricular fibrillation, who had simultaneous embolism of both femoral arteries and received no treatment The initial ischaemic symptoms were of moderate severity but rapidly subsided, and both limbs recovered in 2–3 weeks.

Case No. 37 A E T. 73 years. (F) *Admitted to W.H., 19 5.48*

A woman of 73 years, suffering from hypertensive heart disease with auricular fibrillation Five weeks after a cerebral embolism she had embolism of the left superficial femoral and right popliteal arteries. The popliteal embolism caused no symptoms, but as the heart condition deteriorated a gangrenous ulcer appeared on the left leg and spread rapidly Despite amputation of the limb the general condition continued to decline and the patient died four weeks after the operation.

At autopsy a further occlusion was found in the left deep femoral artery; it appeared to be much older than the other two occlusions *Autopsy*

Case No. 38 A.B 48 years (M) *Admitted to W.H, 3.7 48*

A man of 48 years, suffering from mitral stenosis with regular heart rhythm, who had a cerebral embolism Three years later he had embolism of the left iliac artery. The ischaemic symptoms and signs were not severe, but a small indolent ulcer appeared on the foot This eventually healed and the limb recovered completely.

Case No 39. J C 72 years (M) *Admitted to W H., 20 9.48*

A man of 72 years who recovered well from a myocardial infarction Five months later, while suffering from broncho-pneumonia, he had embolism of the left brachial artery The ischaemic signs were slight and the limb recovered rapidly Forty-two days later the patient died of a second attack of broncho-pneumonia The circulation of the left arm remained adequate to the end *Autopsy*

Case No 40. F W W 66 years (M) *Admitted to W H, 21 9 48*

A man of 66 years with a large arteriosclerotic aneurysm of the right popliteal artery This became occluded by thrombosis, causing an acute ischaemic syndrome, which resulted in gangrene of the lower leg and foot. The limb was amputated and the patient recovered well

Case No 41 M T 70 years (F) *Admitted to W H, 22.9.48*

A woman of 70 years, suffering from hypertensive heart disease with regular heart rhythm and from pneumonia, who had acute occlusion of the left common femoral artery, possibly embolic Gangrene of the leg and foot ensued and the limb was amputated The patient recovered well.

Case No 42 M R 26 years. (F) *Admitted to W.H, 26.10 48*

A woman of 26 years, suffering from mitral stenosis, aortic stenosis, auricular fibrillation and intractable heart failure. Routine examination showed absence of both pulses in the left foot, but she could remember no ischaemic symptoms.

At autopsy, nine months later, an old embolism was found at the bifurcation of the

left popliteal artery. Post-mortem arteriography showed that this was causing no serious obstruction to the circulation of the limb (Figs. 1, 2, 3.) *Autopsy.*

CASE No. 43. E.H. 83 years. (F) *Admitted to W.H., 12.11.48*

An example of 'delayed ischaemic syndrome', produced by left ventricular failure in a woman of 83 years, suffering from hypertensive heart disease, coronary arteriosclerosis and severe anaemia. She had occluded popliteal arteries of at least some months' standing. The collateral circulation, previously adequate, failed with the falling blood-pressure, and this produced an acute ischaemic syndrome in both lower limbs, simulating recent arterial occlusion. *Autopsy*

CASE No. 44. A.P. 60 years. (M) *Admitted to W.H., 22.11.48*

A man of 60 years who had myocardial infarction with congestive heart failure and developed embolism of the left posterior tibial artery. This caused transient pain but no severe ischaemic symptoms. Two months later he had a further embolism in the same limb, occluding the popliteal artery immediately proximal to the old occlusion in the posterior tibial. The second occlusion caused more severe ischaemic symptoms, but these cleared up completely within two weeks, despite progressive cardiac failure, of which the patient ultimately died. Pulses were also noted to be absent in the right foot, though the patient never complained of any symptoms in this limb. Autopsy showed an old occlusion in the right popliteal artery also. *Autopsy*

CASE No. 45. E.T. 79 years. (F) *Admitted to W.H., 17.12.48*

A woman of 79 years, suffering from hypertensive heart disease with auricular fibrillation, who had simultaneous embolism of the right common iliac and left upper popliteal arteries. Nine and a half hours after the onset of the ischaemic symptoms, embolectomy was performed on the right side, apparently successfully, with restoration of the popliteal and foot pulses. Soon after operation the right common iliac was again occluded by a further embolus and gangrene of the limb ensued.

The ischaemic signs in the left lower limb were at first not very severe, but as gangrene developed in the right leg the left leg deteriorated also and gangrene appeared in the foot. *Autopsy*

CASE No. 46. E.T. 61 years. (F) *Admitted to W.H., 28.3.49*

A woman of 61 years, suffering from mitral stenosis with auricular fibrillation and congestive failure, who had separate embolic occlusions of the left superficial femoral and lower popliteal arteries, the deep femoral remaining unobstructed. She died of heart failure, accelerated by intraperitoneal haemorrhage resulting from dicoumarol poisoning. The ischaemic signs in the limb were severe and dermal necrosis occurred in the tips of the toes, but the remainder of the limb survived up to the patient's death, three weeks after the onset of ischaemic symptoms. *Autopsy.*

CASE No. 47. M.O'B. 47 years. (F) *Admitted to W.H., 2.4.49*

A woman of 47 years, suffering from mitral stenosis with auricular fibrillation, admitted to hospital for cerebral embolism. She was treated by rapid digitalisation and after 8 days' treatment showed symptoms of over-dosage. Three days later she had

embolism of the aortic bifurcation. The right femoral pulse was suppressed, but the left, though weakened, remained palpable for four days Gangrene of the right foot and lower leg ensued and the patient died of mesenteric embolism six days after the aortic embolism. The left lower limb survived up to death (Fig 32.) *Autopsy.*

CASE No. 48 B R. 71 years. (M) *Admitted to W.H., 12.5.49*

A man of 71 years, suffering from acute miliary tuberculosis of the lungs and tuberculous pericarditis with heart failure and feeble peripheral circulation. One day before death he developed acute ischaemic signs in the left leg and foot. At autopsy, the left upper popliteal artery was found to be occluded by a compact thrombus having the appearance of an embolus. No cardiac source of possible embolism was demonstrated, but there was an atheromatous ulcer in the left common femoral artery *Autopsy*

CASE No 49 M F.R. 58 years. (F) *Admitted to W H, 14 5 49*

A woman of 58 years, suffering from mitral stenosis and auricular fibrillation, who developed symptoms of over-dosage of digitalis A few days later she had embolism of the left femoral artery The ischaemic symptoms and signs were slight and transient and the limb recovered in two weeks

CASE No 50 M M S 53 years (F) *Admitted to W H, 24 5 49*

A woman of 53 years, suffering from mitral stenosis with auricular fibrillation, under satisfactory control by digitalis for two years She had an attack of severe diarrhoea and three days later there was an embolic occlusion of the left common iliac artery. The ischaemic signs were of moderate severity, but cleared up completely in two to three weeks.

Sixteen months later she had embolism of the right common femoral artery, which caused only minor symptoms, but two days after this there was an embolism of the bifurcation of the aorta The ischaemic signs in the limb with the old common iliac occlusion (left) were trivial, and this led to an erroneous conclusion that the new occlusion was in the right common iliac artery The ischaemia in the right limb was grave, and despite early treatment with heparin and papaverine there was gangrene in the foot and lower leg The patient recovered after amputation through the thigh

Eighteen months after this she had a cerebral embolism and after a further two years an embolism of the left brachial artery The ischaemic signs in this limb were slight and transient, and a weak pulse returned in the radial artery in five days

She died of a new cerebral embolism four months later *Autopsy*

CASE No. 51 D.E C. 29 years. (F) *Admitted to W H., 7 6 49*

A woman of 29 years, suffering from mitral stenosis with auricular fibrillation, who died of congestive heart failure She was found to have old emboli in the right common iliac, right common femoral and left popliteal arteries. According to her history, the ischaemic symptoms had been slight and transient *Autopsy.*

CASE No 52 A J 28 years (F) *Admitted to W.H, 6 7.49*

A woman of 28 years, suffering from subacute bacterial endocarditis, who had embolism of the right common femoral and left common iliac arteries The ischaemic

symptoms were not very severe and soon subsided. About six months later she had *embolism of the bifurcation of the aorta* The symptoms then were more severe, but improved and the patient was able to walk a little for a further two weeks.

About three weeks after the aortic embolism, owing to the advancing heart disease, the general condition became much worse and the blood-pressure fell to a very low level. Gangrene of the lower legs and feet then ensued and the patient died 10 days later.

This was an example of ' relapsing ischaemic syndrome ', produced by failure of a previously adequate collateral circulation when the general blood-pressure suffered a severe fall. *Autopsy*.

CASE No 53 L E.V. 73 years. (F) *Admitted to W.H , 12.7 49*

A woman of 73 years, *suffering from hypertensive heart disease and old myocardial* infarction with auricular fibrillation, who died of cerebral embolism. At some time before death (date uncertain) she had occlusion of the right lower brachial artery, probably embolic The ischaemic signs, which were slight, appeared only shortly before death and were probably due to ' relapsing ischaemic syndrome ' in a moribund patient *Autopsy*

CASE No. 54 A.M H 56 years. (F) *Admitted to W.H , 17.7 49*

A woman of 56 years, suffering from thyrotoxicosis with auricular fibrillation, who had embolic occlusion of the left axillary artery Though the brachial pulse remained palpable for three days, the ischaemic signs were very severe and gangrene up to mid-forearm ensued. The patient recovered after amputation of the limb.

CASE No 55 E E E 79 years (F) *Admitted to W H , 6 8 49*

A woman of 79 years, *suffering from hypertensive heart disease with auricular* fibrillation, who had sudden hemiplegia and embolism of both common femoral arteries, probably occurring about the same time Gangrene of the lower leg and foot ensued on the right (hemiplegic) side, but it seems to have come on gradually, after a delay of several weeks, and may have been due to the declining general condition (' delayed ischaemic syndrome ') On the left side, though the internal iliac artery was occluded as well as the common femoral, the limb survived up to the patient's death, several weeks later *Autopsy*

CASE No 56 A J H. 78 years. (F) *Admitted to W H , 20.8.49*

A woman of 78 years, suffering from myocardial infarction with intermittent auricular fibrillation. One month after the infarction, she had embolism of the left axillary artery and the right femoral artery, occurring almost simultaneously. The ischaemic symptoms were moderately severe, but rapidly improved and cleared up almost completely *in three to four weeks.*

CASE No. 57. E B. 56 years. (F) *Admitted to W H., 19 9 49*

A woman of 56 years, suffering from deep thrombo-phlebitis of the left lower limb with recurrent pulmonary embolism. Thrombosis of the main deep veins was accompanied by a mild acute ischaemic syndrome in the same limb. The pulses were suppressed, arterial oscillations were reduced and the limb became cyanosed.

The ischaemic symptoms, apparently due to arterial spasm, receded rapidly under treatment with papaverine and anticoagulants and the arterial pulses soon returned. The subsequent course was that of a slowly resolving deep vein thrombosis.

CASE No. 58 K.K. 38 years (F) *Admitted to W.H., 27.10 49*

A woman of 38 years, suffering from rheumatic mitral and aortic valvular disease, but with regular heart rhythm, became over-digitalised, and while in this condition she had a cerebral embolism, accompanied by embolism of the right brachial and right popliteal arteries. There were no noteworthy ischaemic symptoms or signs, and the distal pulses returned in both limbs two to three weeks later

CASE No. 59. C.McL 65 years (F) *Admitted to W H., 12.1 50*

A woman of 65 years, suffering from rheumatic mitral stenosis and auricular fibrillation, combined with syphilitic disease of the aorta and the larger limb arteries and extensive thrombosis of the aorta Digitalis treatment was initiated and soon afterwards she had acute ischaemic syndromes, first in the left arm and subsequently in both lower *limbs simultaneously. The ischaemic symptoms were not very severe, and despite increas*ing heart failure all three affected limbs survived, though there was a necrotic ulcer in the pressure area of the left calf At autopsy, occlusions, probably embolic, were found in the left common iliac and right popliteal arteries No occlusion was found in the arteries of the left arm, but they showed extensive syphilitic changes. *Autopsy.*

CASE No. 60 J P 57 years (F) *Admitted to W.H , 15 6.50*

A woman of 57 years, suffering from mitral stenosis with subacute bacterial endocarditis, who had embolism of the left axillary and left popliteal arteries The ischaemic symptoms in the upper limb were mild and cleared up completely in four weeks. The radial pulse returned in three days, but oscillometric readings were still much reduced three weeks later The popliteal embolism caused no symptoms whatever and the dorsal pedal pulse returned in two days The patient recovered under treatment with penicillin.

CASE No 61 H R 68 years (F) *Admitted to W H , 6 8 50*

A woman of 68 years, suffering from mitral stenosis with auricular fibrillation, complicated by hypertension, arteriosclerosis, bronchitis and diabetes mellitus. She had multiple occlusions of the lower limb arteries, and the multiplicity and situations of these occlusions, together with the evidence of visceral embolism, indicated that they were embolic.

She had severe chronic ischaemic symptoms for many months, but escaped gangrene in the left leg and developed it only terminally in the right, when dying of bronchitis and heart failure *Autopsy.*

CASE No 62. F P 59 years (F) *Admitted to W.H., 10.8 50*

A woman of 59 years, suffering from mitral stenosis with auricular fibrillation, who had embolism of the left common iliac artery She was admitted to hospital one day after onset and treated with heparin and dicoumarol, but gangrene ensued and the limb was amputated It was noted at this time that the popliteal and foot pulses were absent in the right lower limb also, but the ischaemic signs on this side were slight.

Nine months later she had embolism of the right common iliac artery. On this occasion the ischaemic signs were only of moderate severity and rapidly subsided within three weeks.

CASE NO. 63 W.J H 60 years. (M) *Admitted to W H., 24 4.51*

A man of 60 years, suffering from mitral stenosis with auricular fibrillation, treated for congestive heart failure On admission to hospital, all peripheral pulses were noted to be present. Thirteen days later he showed signs of over-dosage of digitalis. Routine examination then showed absence of both pulses in the right foot He appears to have had asymptomatic embolism of the popliteal artery

CASE NO. 64. H F 30 years (M) *Admitted to W H., 2 6 51*

A man of 30 years, suffering from mitral stenosis with auricular fibrillation After four months' treatment with digitalis he had embolism of the aortic bifurcation and multiple embolisms of most of the main arteries of both lower limbs. He died 4½ hours after the onset of the ischaemic symptoms, and at autopsy nearly all the thrombi were of very recent appearance There was one old adherent embolus in the right popliteal artery. *Autopsy*

CASE NO. 65 F.A.C 52 years. (F) *Admitted to W.H , 10 10.51*

A woman of 52 years, suffering from mitral stenosis with auricular fibrillation, who became over-digitalised and soon afterwards had embolism of the left common iliac artery (preceded by transient symptoms of occlusion of the aortic bifurcation). The ischaemic symptoms were severe, but soon improved and subsided in a few weeks. Slight chronic ischaemic symptoms have persisted for six years.

CASE NO. 66. M M.H. 64 years. (F) *Admitted to W H., 24 11 51*

A woman of 64 years, suffering from mitral stenosis with auricular fibrillation, who developed signs of over-dosage of digitalis Soon after this she had an embolism of the right brachial artery with ischaemic symptoms of moderate severity Embolectomy was performed at six hours, pulsation was restored in the radial artery and the limb rapidly recovered.

Treatment with digitalis was resumed after operation and further symptoms of over-dosage appeared. Seventeen days after operation the patient died suddenly, and at autopsy she was found to have cerebral embolism and very recent embolisms of the superior mesenteric and several limb arteries. Recently formed, unattached thrombi were present in the left auricle. *Autopsy*

CASE NO. 67. B F 72 years (M) *Admitted to W.H., 3.3.52*

A man of 72 years with a history of acute gangrene of the right leg two years previously, admitted to hospital suffering from left hemiplegia and acute ischaemic syndrome in the left leg. A diagnosis of arteriosclerotic thrombosis was made, but proved to be erroneous, for autopsy revealed four separate embolic occlusions of main peripheral arteries at points of bifurcation, resulting from old myocardial infarction with intra-cardiac thrombosis. *Autopsy*.

CASE NO. 68. P.J P. 25 years. (F) *Admitted to W H, 5 7.52*

A woman of 25 years, suffering from mitral stenosis and subacute bacterial endocarditis, who had embolism at the bifurcation of the right brachial artery. The symptoms were mild, but included slight ischaemic damage to the proximal muscles of the forearm. Recovery of the limb was rapid and complete

CASE NO. 69. E.D 62 years. (F) *Admitted to W H, 5.12.52*

A woman of 62 years, suffering from mitral stenosis with auricular fibrillation, had embolism of the left common iliac artery, followed by embolism of the right external iliac, and in each case the limb recovered well. One year later she had an embolic occlusion of the right axillary artery, and though the radial pulse returned within three weeks there was severe ischaemic fibrosis of the muscles of the forearm and hand

Three months after the axillary embolism she died of subarachnoid haemorrhage, and autopsy showed that there were occlusions of much earlier date at two separate levels in the right brachial artery In this case the prior occlusion appears to have aggravated the effects of the later one. (Figs 4, 5, 6, 34) *Autopsy.*

CASE NO 70 H H 64 years (F) *Admitted to W H, 24 1 53*

A woman of 64 years, suffering from mitral stenosis with auricular fibrillation, and with a history of two cerebral embolisms, who had acute ischaemic syndrome in the right arm, probably due to embolism of the axillary artery The initial symptoms were moderately severe and included slight ischaemic damage to the thenar muscles, but they soon improved and cleared up completely in three weeks All pulses in the limb had returned seven days after onset Both pulses were also found to be absent in the left foot, but the patient remembered no ischaemic symptoms in this limb

CASE NO 71 J.S 74 years (M) *Admitted to W H, 9 2 53*

A man of 74 years, suffering from arteriosclerosis and hypertension, who had sudden severe dyspnoea, precordial pain and collapse, accompanied by acute ischaemic signs in both lower limbs, where all arterial pulses were found to be absent With recovery from the acute collapse, the ischaemic signs regressed but reappeared terminally when he died of heart failure, 27 days later. Autopsy revealed an old thrombotic occlusion of the aorta, obviously of much longer standing than the acute ischaemic symptoms This was an example of 'delayed ischaemic syndrome', precipitated by failure of a previously adequate collateral circulation during a state of cardiac collapse resulting from massive pulmonary embolism *Autopsy*

CASE NO. 72 M McA 15 years. (M) *Admitted to W H, 14 5 53*

A boy of 15 years, suffering from acute staphylococcal endocarditis, who had embolism of both popliteal arteries No ischaemic symptoms or signs were noted during life *Autopsy*

CASE NO 73. A F. 52 years (F) *Admitted to W H, 30 5.53*

A woman of 52 years, suffering from gastric carcinoma and myocardial infarction with intracardiac thrombosis. She had embolism of the right axillary artery, and though pulse deficiencies were noted there were at first no ischaemic signs of any severity.

Twenty-four hours later the general condition deteriorated and there was a sharp fall of blood-pressure Soon after this, signs of ischaemic damage appeared in the muscles of the forearm, followed shortly before death by extensive extravasation staining of the limb, presaging massive gangrene. *Autopsy*

CASE No 74. E S. 53 years (M) *Admitted to W.H , 12.6.53*

A man of 53 years, suffering from bronchial carcinoma with extensive metastases in lymph nodes and pericardium and complicated by myocardial infarction. Thrombi formed on the mitral valve and there was embolism of the left popliteal artery

At first the collateral circulation appeared adequate but as the patient's general condition declined, gangrene of the ankle and foot appeared, shortly before death It was accompanied by superficial gangrene of the tip of the nose. *Autopsy*

CASE No 75 M T. 68 years. (F) *Admitted to W H , 16.11 53*

A woman of over 60 years, suffering from mitral stenosis with auricular fibrillation and hypertension, who had major embolic occlusions successively in all four limbs. One of these occlusions, and also a cerebral embolism, occurred following over-dosage of digitalis

In the upper limbs the ischaemic symptoms were of moderate severity but recovery *was rapid The patient could remember no ischaemic symptoms in either of the lower* limbs

She developed left ventricular failure, gradually deteriorated, and died seven months after the last of the limb embolisms The circulation in all four limbs remained good to the end (Figs. 7, 8, 9, 35) *Autopsy*

CASE No 76 M A M 62 years. (F) *Admitted to W H., 25 1 54*

A woman of 62 years, suffering from pulmonary and hypertensive heart disease with auricular fibrillation, who had cerebral embolism, followed by embolism of the left *common iliac artery Gangrene of the lower leg and foot ensued After amputation* of the limb she improved considerably, but died of a second cerebral infarction two months later Autopsy showed that there had been a prior occlusion of long standing in the left external iliac artery (Fig 36) *Autopsy.*

CASE No. 77 C K 66 years (F) *Admitted to W H , 9 12 53*

A woman of 66 years, suffering from mitral stenosis with auricular fibrillation, who had embolism of both popliteal arteries The ischaemic symptoms in the left leg were slight and transient, but in the right foot there was slight superficial dermal necrosis, *which took several* weeks to heal. Both limbs eventually recovered completely.

She also had two slight cerebral embolisms and synchronously with the second one there was an extremely transient ischaemic episode in the left upper limb. This resolved suddenly, with return of the radial pulse, actually while the brachial artery was being palpated The sudden improvement may have been due to embolic migration

CASE No. 78. L E T. 66 years. (F) *Admitted to W.H., 24.2.54*

A woman of 66 years, suffering from hypertensive and pulmonary heart disease with auricular fibrillation and congestive failure, who had embolism of the left popliteal

artery. The ischaemic symptoms were of moderate severity but rapidly subsided, and the limb recovered completely. When she was first examined, three days after onset, the popliteal and femoral pulses were absent, but these pulses later returned, the femoral at ten days and the popliteal at eighteen days. This indicates that there was spasm of the arterial trunk, extending proximally from the embolus, but it did not prevent rapid recovery.

Three days after admission to hospital the patient had symptoms of over-dosage of digoxin, and one day later she had embolism of the right superficial femoral artery On this occasion there was no evidence of arterial spasm The symptoms were not severe and the limb recovered completely in two weeks She died of heart failure three months later. (Fig. 24.) *Autopsy*

CASE NO 79. E.N. 51 years (F) *Admitted to W H , 13 8.54*

A woman of 51 years, suffering from mitral stenosis with auricular fibrillation, who had embolism of the left popliteal artery. The ischaemic symptoms were moderately severe at the onset, but passed off rapidly, and the limb recovered completely in a week A weak pulse returned in the dorsal pedal artery 15 days after onset

CASE NO. 80. J S. 21 years. (F) *Admitted to W H , 19.9 54*

A woman of 21 years, suffering from myocarditis with arrhythmia and intracardiac thrombosis, who developed congestive failure late in pregnancy and had embolism of the aortic bifurcation and the left common iliac and common femoral arteries

Collateral circulation at first appeared to be adequate, but the heart condition deteriorated and the collateral circulation then failed, with resulting gangrene, at first in the left leg and terminally in the right *Autopsy*

CASE NO. 81. H.W 48 years (F) *Admitted to W H , 24 10 54*

A woman of 48 years, suffering from mitral stenosis with auricular fibrillation, under good control by digitalis and without any symptoms of heart failure She had embolism of the bifurcation of the aorta and though the initial symptoms were bilateral, those on the right were mild and transient; this limb recovered completely On the left side the ischaemic signs were initially severe but steadily improved, and nine days after their onset the limb appeared to be recovering The next day there was a sudden recurrence of severe ischaemia and gangrene of part of the foot ensued, 15 days after onset

A weak femoral pulse returned in the limb which became gangrenous, but not in the surviving limb (Fig. 37) *Autopsy*

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PRINTED IN GREAT BRITAIN BY ROBERT MACLEHOSE AND CO LTD
THE UNIVERSITY PRESS, GLASGOW